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September 29, 2006

Mr. David Staudt
Centers for Disease Control and Prevention
Acquisition and Assistance Field Branch
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Subject: Contract No. 200-2004-03805, Task Order 1: *Oak Ridge National Laboratory Site Profile Review*, SCA-TR-TASK1-0013

Dear Mr. Staudt:

SC&A is pleased to submit to NIOSH and the Advisory Board our draft *Oak Ridge National Laboratory Site Profile Review*. Please note that Attachment 2 of this report, *Site Expert Interview Summary*, is currently being reviewed by the Site Experts who participated in the interview, and will be forwarded under separate cover as soon as it has been approved.

If you have any questions or comments on this report, please contact John Mauro at 732-530-0104. We look forward to discussing this draft report with NIOSH and the Advisory Board.

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

Oak Ridge National Laboratory Site Profile Review

Contract No. 200-2004-03805
Task Order No. 1
SCA-TR-TASK1-0013

Prepared by

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Disclaimer

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Task Manager: _____ Date: _____ Joseph Fitzgerald	Supersedes: N/A
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ACRONYMS AND ABBREVIATIONS

Advisory Board	Advisory Board on Radiation and Worker Health
Al	Aluminum
ANP	Aircraft Nuclear Propulsion
AP	Anterior-Posterior
AEC	Atomic Energy Commission
AMAD	Activity Median Aerodynamic Diameter
Bq	Becquerel
BSR	Bulk Shielding Reactor
CATI	Computer-Assisted Telephone Interview
CEF	Critical Experiments Facility
CEDR	Comprehensive Epidemiologic Data Resource
CEDS	Centralized External Dosimetry System
CER	Center for Epidemiologic Research
CFR	*Code of Federal Regulations*
Ci	Curie
CXR	Chest X-ray
DCF	Dose Conversion Factor
D&D	Decontamination and Decommissioning
DOSAR	Dosimetry Applications Research Calibration Laboratory
DR	Dose Reconstruction
DOE	Department of Energy
DOELAP	Department of Energy Laboratory Accreditation Program
dpm	Disintegrations per Minute
EC	Electronic Capture
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
ESE	Entrance Skin Exposure
FCAF	Fuel Cycle Alpha Facility
GSD	Geometric Standard Deviation
HFIR	High Flux Isotope Reactor
HHIRF	Holified Heavy Iron Research Facility

HP	Health Physics
HPRR	Health Physics Research Reactor
HRE	Homogeneous Reactor Experiment
HTO	Tritiated Water
HVL	Half Value Layer
IAAP	Iowa Army Ammunition Plant
ICRP	International Commission on Radiological Protection
IMBA	Integrated Modules for Bioassay Analysis
INEEL	Idaho National Engineering and Environmental Laboratory
IREP	Interactive RadioEpidemiological Program
keV	Kilo electron Volt
LAM	Local Air Monitoring
LANL	Los Alamos National Laboratory
LAT	Lateral
LITR	Low Intensity Test Reactor
LOD	Limit of Detection
µCi	Microcurie
MAC	Maximum Allowable Concentration
MAP	Mixed Activation Products
MCW	Mallinckrodt Chemical Works
MDA	Minimum Detectable Activity
MDC	Minimum Detectable Concentration
MDL	Minimum Detectable Dose
MeV	Mega-electron Volt
MFAP	Mixed Fission/Activation Products
MFP	Mixed Fission Products
mR	Milliroentgen
mrad	Millirad
mrem	Millirem
mrep	Millirep
MSRE	Molten Salt Reactor Experiment
MT	Metal Tritides

n-p	Neutron-to-photon ratio
NCRP	National Council on Radiation Protection and Measurements
NIOSH	National Institute for Occupational Safety and Health
NOCTS	NIOSH-OCAS Computer Tracking System
NTA	Eastman Kodak Nuclear Track Film Type A
NTS	Nevada Test Site
NU	Natural Uranium
OBT	Organically Bound Tritium
OCAS	Office of Compensation Analysis and Support
OER	Occupational Exposure Record
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Research Reactor
ORAU	Oak Ridge Associated Universities
ORELA	Oak Ridge Electron Linear Accelerator
ORIC	Oak Ridge Isochronous Cyclotron
ORISE	Oak Ridge Institute for Science and Education
OSHA	Occupational Safety and Health Administration
OTIB	ORAU Technical Information Bulletin
OW	Open Window
PA	Posterior-Anterior
PAS	Personal Air Sampling
PCA	Pool Critical Assembly
PFG	Photofluorography
PIC	Pocket Ionization Chamber
POC	Probability of Causation
PROC	Procedure
ppm	Parts Per Million
RaLa	Radioactive Lanthanum
R&D	Research and Development
RCT	Radiological Control Technician
REDC	Radiochemical Engineering Development Center
RFP	Rocky Flats Plant

RU	Recycled Uranium
SC&A	S. Cohen and Associates
SRS	Savannah River Site
SRDB	Site Research Database
SSD	Source to Surface Distance
TB	Tuberculosis
TBD	Technical Basis Document
TDF	Transuranium Decontamination Facility
TIB	NIOSH Technical Information Bulletin
TLD	Thermoluminescent Dosimeter
TSR	Tower Shielding Reactor
WISPR	NIOSH worker input database
X-10	Oak Ridge National Laboratory
Y-12 Plant	Y-12 National Security Complex

1.0 EXECUTIVE SUMMARY

This report provides the results of an independent audit conducted by S. Cohen and Associates (SC&A, Inc.) of the technical basis documents (TBDs) developed by the National Institute for Occupation Safety and Health (NIOSH) that make up the site profile for the Oak Ridge National Laboratory (ORNL). This audit was conducted during the period February 1, 2006–September 15, 2006, in support of the Advisory Board on Radiation and Worker Health (Advisory Board) in the latter's statutory responsibility under the Energy Employees Occupational Illness Compensation Program Act (EEOICPA) to conduct such reviews, and advise the Secretary of Health and Human Services on the "completeness and adequacy" of the EEOICPA program.

ORNL is located on the Oak Ridge Reservation, along with the Y-12 National Security Complex (Y-12) and the Oak Ridge Gaseous Diffusion Plant (K-25). The main laboratory area of ORNL is in Bethel Valley. Other ORNL research facilities are located at an adjacent site in Melton Valley and at the Y-12 Plant (DOE 1990). The Site Description TBD (Fleming 2006b, pp. 10–11) provides the following summary of the scope of the nuclear activities conducted at the ORNL:

> *Since its operations began in 1943, the mission of Oak Ridge National Laboratory (ORNL) has been to conduct research and development (R&D) and production missions in support of DOE and its predecessor agencies. Much of the earliest site work was devoted to the development and operation of the original plutonium production reactor and associated chemical separation facility to test the larger production reactors that were being built on the Hanford Site. The Graphite Reactor produced gram quantities of plutonium and later fission products [e.g., radioactive lanthanum (RaLa)]; other types of radioactive materials were separated in other site facilities. Waste control technologies during early site operations were in their infancy, and much of the current knowledge of transport of radionuclides in the environment was obtained during this time. The ability to detect, identify, and quantify radiation types and exposures were progressing along with new technologies being discovered in radioisotope production. Much of the information gained during the early years at ORNL was used for the design of future U.S. Atomic Energy Commission (AEC)/DOE facilities and detection systems. Waste radioactive material was released from early site operations as gaseous, liquid, and solid effluents with little or no pretreatment. Methods were later developed to capture many of the contaminants at their source and to reduce overall plant emissions. In some cases, this increased direct exposures to individuals in the immediate area and created locations in which incidents and spills occurred.*
>
> *During the more than 60 years of operations at the site, facilities have been constructed, operated, decontaminated, and decommissioned based on need.*

- *The operation of the Graphite Reactor for producing plutonium and other radioisotopes*

- *The development and refinement of chemical processes to separate plutonium, uranium, and thorium from irradiated fuel*

- *Chemical separation of RaLa from irradiated fuel slugs for use in implosion dynamics studies at Los Alamos National Laboratory*

- *Operation of facilities for the separation, packaging, and distribution of radioisotopes for government and commercial use*

In addition, ORNL developed new reactor technologies. The Laboratory tested different reactor designs (pool, pressurized-water, boiling-water, liquid-metal, gas-cooled) that were either scrapped or developed further elsewhere. Reactors operated at ORNL include the Low-Intensity Test Reactor (LITR), Critical Experiments Facility [CEF, at the Y-12 National Nuclear Security Complex (Y-12)], Bulk Shielding Reactor (BSR)/Pool Critical Assembly (PCA), Oak Ridge Research Reactor (ORR), Tower Shielding Reactor (TSR), Health Physics Research Reactor (HPRR), Homogeneous Reactor Experiment (HRE), Aircraft Nuclear Propulsion (ANP) Program, the High Flux Isotope Reactor (HFIR), and the Molten Salt Reactor Experiment (MSRE).

SC&A's review focused on the six TBDs that make up the ORNL site profile. These address introduction, site description, occupational internal dose, occupational external dose, occupational medical dose, and occupational environmental dose, as they pertain to historic radiation exposure of ORNL workers. These TBDs are dated from 2004–2006. As "living" documents, TBDs are constantly being revised as new information, experience, or issues arise. A complete list of the ORNL TBDs, as well as supporting documents, that were reviewed by SC&A is provided in Attachment 1.

SC&A's review process included a review of the TBDs, a visit to Oak Ridge, Tennessee, to conduct interviews with site experts and identify documents for data retrieval, reviews of retrieved ORNL and other historic records, and an exchange of questions and answers, in addition to TBD-specific conference calls, between SC&A and its NIOSH and Oak Ridge Associated Universities (ORAU) counterparts. The TBDs were evaluated for their 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).

The Occupational Medical Dose TBD, ORAUT-TKBS-0012-3 (Fleming 2004), provides little documentation to support the assumed techniques, and protocols applied to calculate the dose, which is mainly derived from Cardarelli et al. 2002, are accurate. NIOSH believes that when no information is readily available about the energy spectrum, it is reasonable to use the assumptions for dose conversion factors (DCFs) that are presented in the Implementation Guide.

The Occupational Environmental Dose TBD (Burns 2004b) appears to rely on emission and measurement data; however, it does not indicate the model used for calculations. The TBD generally discusses particle size; however, the actual particle size assumptions for assignment of internal dose have not been provided. No consideration has been given to the deficiencies in the stack and ambient air sampling systems; however, there is a heavy reliance on these systems to determine unmonitored worker dose. Exposures considered are limited to I-131, H-3 (starting 1967), Kr-85, Xe-133, and mixed fission products (MFPs) (optional), while diverse radionuclides were handled and potentially released at the site. There has been no consideration of potential doses from the release of large uranium particles. Overall, SC&A believes that further investigation into environmental source terms and pathways is needed.

The Occupational External Dose TBD (Burns and Mohrbacher 2004) may result in an underestimate of neutron dose. Neutron dose is determined from neutron track emulsion type A (NTA) film results and is modified with a correction factor. Some facility-specific neutron energy bands are provided; however, in some facilities, the entire spectrum is essentially below the practical 1-MeV detection limits of NTA film used in the workers' badges. From the information in current Occupational External Dose TBD, ORAUT-TKBS-0012-6 (Burns and Mohrbacher 2004), it is not obvious that the dose reconstructor has sufficient detailed correction factors/instructions available to correct for the unmonitored neutron doses resulting from neutrons with less than 1 MeV of energy at the numerous facilities at ORNL that produced neutron exposures through the years.

Information available for the dose reconstruction in the early years is limited, inadequate, and in some cases, not available. External monitoring for 1943–1944 was limited to the use of pocket ionization chambers (PICs), with some experimental badges worn. There is a lack of clear discussion on how these monitored and unmonitored doses are derived during this time period. Furthermore, the Occupational External Dose TBD (Burns and Mohrbacher 2004) questions the validity of these data. The monitoring practices for the years prior to 1951 required further investigation to determine if all exposed workers were monitored during this time period. In terms of internal exposure, there was an absence of routine internal monitoring until 1949. Early bioassay data was limited to plutonium and strontium, although other radionuclides were being handled even prior to 1949.

The Occupational Internal Dose TBD lacks guidance on how to assign dose to radionuclides other than transuranics, uranium, activation products, and fission products. As indicated by site experts, ORNL handled almost everything on the periodic table at one point or another. There has been no screening presented to demonstrate that the secondary radionuclides, particularly accelerator- and reactor-produced, are of no dose consequence to the workers. Although ORNL handled uranium and radium in the early years, no consideration was given to occupational radon exposure. Information was not provided on the activity fractions for plutonium and thorium. Activity fractions for plutonium provide critical information for the assessment of dose from americium as an impurity. Dose from non-traditional chemical forms of radionuclides, such as high-fired oxides and tritides, were not considered. Finally, an adequate rationale for assumption of Am-241 in the case of transplutonium bioassay rather than Cm-244 was not provided.

Issues presented in this report are sorted into the following categories, in accordance with SC&A's review procedures:

(1) Completeness of data sources
(2) Technical accuracy
(3) Adequacy of data
(4) Consistency among site profiles
(5) Regulatory compliance

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 five review criteria. Several of the issues were designated as primary findings, because they represent key deficiencies in the TBDs that need to be corrected, and which have the potential to substantially impact at least some dose reconstructions. Others have been designated "secondary findings" to both connote their importance for the technical adequacy and completeness of the site profile, and to indicate that they have been judged by SC&A to have relatively less influence on dose reconstruction or the ultimate significance of worker doses so estimated.

1.1 SUMMARY OF STENGTHS

Both the internal and external dose TBDs provided an extensive history of the internal and external monitoring program at ORNL. The NIOSH/ORAU team is aware of gaps in the TBDs, and has plans to investigate exposure to radon, americium as an impurity, and tritides. Recent revisions to the ORNL Site Description TBD captured a number of facilities that were missed in the original version of the site description, and provided further information on ORNL processes and operations. One benefit of this revision was the inclusion of all buildings mentioned by site experts as being missing from the original revision.

1.2 SUMMARY OF FINDINGS

Finding 1: Incomplete Dose Data for the Earlier Years. Information available for dose reconstruction in the early years is limited, inadequate, or in some cases, not available. External beta/gamma monitoring with film badges did not occur until June 1944, while routine neutron monitoring was not available until 1949. The neutron dose is reliant on application of a neutron-proton (n-p) ratio to the photon dose, yet the TBD questions the dose results from 1943–1944. Bioassay was not routinely available prior to 1949, and then only for a few radionuclides. Table 5A-2, page 39, of the Occupational Internal Dose TBD (Bollenbacher et al. 2006) provides minimum detectable activity (MDA) values that have been determined for gross alpha, gross beta, and 16 radionuclides found in urinalysis sampling, and gross alpha and 4 radionuclides found in fecal sampling. A method for identifying workers and assigning missed dose for those potentially exposed to all the assorted radionuclides for which MDAs have been determined (Table 5A-2, page 39) is lacking in this document. No consideration was given to early issues with significant beta exposures, which caused skin erythema. Consideration of dose from uranium particle releases and their subsequent deposition on the skin was not evaluated in the

TBD. For 1944–1947, the TBD relies on air sampling data; however, very little information is provided related to its collection and analysis. Further evaluation should be provided to make sure this approach is bounding for unmonitored acute and chronic intakes.

Finding 2: Inadequate Consideration of Missed Dose from Other Radionuclides. Although it acknowledges their existence, the Occupational Internal Dosimetry TBD ORAUT-TKBS-0012-5 (Bollenbacher et al. 2006) does not adequately address potential doses from secondary or so-called "exotic" radionuclides. The focus of the TBD is on "radionuclides likely to produce a measurable internal dose," including uranium, activation products, fission products, and transuranics. Numerous radionuclides were handled at ORNL ranging in quantities from fractions of a gram to kilograms. Radionuclides for which co-worker dose is assigned included strontium, uranium, plutonium, Am-241, Cs-137, Ce-144, and Ru-106 (Kennedy 2005). Potential exposures to reactor- and accelerator-produced radionuclides have not been adequately considered. The TBD does not try to ascertain when radionuclides were present, in what quantities they were handled, and whether there were suitable methods available for monitoring these radionuclides.

Finding 3: Problems with Neutron Doses. In view of several statements made in the Occupational External Dose TBD (Burns and Mohrbacher 2004), the use of NTA film to monitor neutron doses at ORNL raises several areas of concern. For example, page 23 of the TBD mentions that neutron energy spectra and neutron exposure data before the late 1980s is sparse, and that information is particularly lacking for many of the reactors that operated at ORNL early in its history. If n-p values are used instead of NTA dose records, these concerns are still valid, because using n-p values depend on a detailed knowledge of the gamma and neutron doses, and neutron energy spectra at each work location as a function of time.

Finding 4: Lack of Information Concerning Selection of Workers for Badging. The Occupational External Dose TBD (Burns and Mohrbacher 2004) does not provide sufficient details concerning who was badged and when, to ensure that workers were sufficiently monitored to allow for technically sound dose reconstruction. Page 11 of the TBD states that initially only employees required to work in restricted areas more than 3 days per week were issued beta-gamma monitoring, and that as late as 1956, there were no strict enforcement policies concerning the wearing of monitoring badges. Apparently, the workers that entered restricted areas only 1 or 2 days per week did not received badges or any dose of record. Table 6-2, page 16, of the TBD provides a list of the characteristics of dosimeters from 1944 to present worn by *radiation* workers at ORNL, but does not describe what defined a radiation worker. The TBD needs to further refine who was (and was not) monitored and how those selections were made in order to be able to determine the adequacy of the dose records.

Finding 5: Lack of Dose Assignment Procedure for Unmonitored Worker. The Occupational External Dose TBD (Burns and Mohrbacher 2004) does not provide a defined procedure to assign dose to unmonitored workers. Section 6.5.1 briefly mentions limits of detection (LOD) and provides Table 6-24, page 69, listing the LOD and exchange frequency as a function of time. However, this should only be applied to the dose missed by the dosimeter worn by a worker, not the dose missed because a worker was not badged. This applies to neutron as

well as photon and beta doses. During these early years, an unmonitored worker could have received dose without management or the worker being fully aware of the hazards. The TBD needs to provide technically sound dose reconstruction procedures for assigning doses to unmonitored workers, especially in the early years (1943–1960s), when radiation hazards were not always recognized or effectively addressed.

Finding 6: Lack of Data Validation and Verification. The validation and verification of the data used in dose reconstruction has not adequately been completed. There are indications that additional bioassay data exist that are not reflected in the database obtained by ORAU for the calculation of MDAs. For example, we became aware that the ORNL has not fully consolidated all the occupational exposure records, indicating that some records may not be complete. Also, the completeness and accuracy of the external dosimetry data may require further verification to ensure field-recorded dose results were integrated into occupational exposure records (OERs). This adds to uncertainty of these data. Finally, the environmental air sampling data ratios used in the development of co-worker dose from Ru-106, Ce-144, and Cs-137 should be further justified.

Finding 7: The TBD Fails to Adequately Define and Assess Occupational Medical Exposure. The current medical exposure and dose guidelines, as presented in (Kathren 2003), go a long way in assuring that all occupational medical exposures are reasonably included in determining the overall dose estimations for claimants. Unfortunately, the interpretation to date by the contractor (ORAU) has not been applied too conservatively to be claimant favorable. The occupational medical dose TBD (Fleming 2006a) assumes an interpretation that also has been considered and applied at other sites, such as the Mound Plant and Los Alamos National Laboratory (LANL), Paducah, and Pinellas. To this extent, the assumption that medical procedures are limited to only one pre-employment chest x-ray and chest x-rays that are part of routine physical exams may substantially underestimate worker medical exposure when evaluating occupational medical exposure.

Finding 8: Techniques and Protocols Increase Uncertainty of DCFs listed in the TBD. The Occupational Medical Dose TBD (Fleming 2006a) provides little documentation to support the assumed techniques and protocols applied to calculate the dose, which is mainly derived from NCRP Report 102. The TBD states that a posterior-anterior (PA) chest x-ray was typically the only view taken. It is an undocumented assumption in the TBD that exams required only a PA view. SC&A has inquired whether definitive protocol existed to validate that chest exams possibly included PA views and lateral (LAT) views on a limited basis. NIOSH has acknowledged in other TBD reviews that the lack of verifiable protocols is a generic problem at many sites, has planned to search all available records, and will include pertinent records and references in any future revision of this section of the TBD. The Occupational Medical Dose TBD is also deficient in that little documentation exists to validate x-ray protocols, equipment maintenance, and upkeep records.

Finding 9: Frequency and Type of X-ray Exposure is Uncertain. The Occupational Medical Dose TBD in Section 3 provides no documentation or references to support the assumption that only a limited group of workers received annual x-ray exams after 1970. To the contrary, up until about 1985, most DOE sites performed chest x-rays almost on a voluntary basis. DOE

medical program reviews documented during the early 1990s showed many sites still used chest radiography as a general screening exam. Most workers accepted chest x-rays, even though the job did not require it. Also, the assumption that workers in special exposure categories, such as beryllium workers, were given chest x-rays only as part of their routine physical is not well-documented and not consistent with special screening guidelines. The TBD applies no conservative assumption to cover such exams.

Finding 10: Inadequate Consideration of Environmental Dose from Radionuclides Other than I-131 and Tritium. The Occupational Environmental Dose TBD (Fleming 2006a) focuses on onsite airborne I-131 concentration, onsite airborne concentration of MFPs, onsite airborne concentrations of tritium, and onsite exposure rate data. Reactors' releases and waste farms data are not adequately considered.

2.0 SCOPE AND INTRODUCTION

The review of the Oak Ridge National Laboratory (ORNL) Site Profile was conducted from February 1, 2006–September 15, 2006, by a team of SC&A health physicists and technical personnel.

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 ORNL:

- ORAUT-TKBS-0012-1, *Technical Basis Document for Oak Ridge National Laboratory – Introduction Rev. 00,* August 11, 2004 *(*Burns 2004a)

- ORAUT-TKBS-0012-2, *Technical Basis Document for Oak Ridge National Laboratory – Site Description Rev. 01,* August 30, 2006 (Fleming 2006b)

- ORAUT-TKBS-0012-3, *Technical Basis Document for Oak Ridge National Laboratory – Occupational Medical Dose Rev. 01 PC-1,* July 21, 2006 (Fleming 2006a)

- ORAUT-TKBS-0012-4, *Technical Basis Document for Oak Ridge National Laboratory – Occupational Environmental Dose Rev. 00,* May 7, 2004 (Burns 2004b)

- ORAUT-TKBS-0012-5, *Technical Basis Document for Oak Ridge National Laboratory – Occupational Internal Dose Rev. 00 PC-1,* May 30, 2006 (Bollenbacher et al. 2006)

- ORAUT-TKBS-0012-6, *Technical Basis Document for Oak Ridge National Laboratory – Occupational External Dose Rev. 00,* August 11, 2004 (Burns and Mohrbacher 2004)

During the course of SC&A's review, there was a substantial revision of the Site Description TBD. This revised TBD provided additional information on the site, including some facilities identified by workers as missing from Rev. 0. A minor revision of the Occupational Medical Dose TBD was issued at the mid-point of the review. These documents are supplemented by

technical information bulletins (TIBs), which provide additional guidance to the dose reconstructor. A complete list of these documents is available in Attachment 1.

Implementation guidance is also provided by so-called "workbooks," which have been developed by NIOSH for selected sites to provide more definitive direction to the dose reconstructors on how to interpret and apply TBDs, as well as other available information.

Beyond the conduct of its independent interviews of site experts and former workers, the SC&A team is aware of and has requested access to a NIOSH database called "WISPR," which contains NIOSH/ORAU-conducted interviews. It was the team's understanding that use of the database requires training to be provided by ORAU. A formal request has been made for training and access to the database. In the meantime, SC&A has reviewed available information from worker outreach meetings and public comments during the Advisory Board meetings in Oak Ridge and Knoxville, Tennessee. These references are sources of information for the WISPR database. An addendum to this report will be provided, based on the results of an evaluation of the information found in the WISPR database as necessary.

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

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

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

The review is directed at "sampling" the site profile analyses and data for validation purposes. The review does not provide a rigorous quality control process whereby actual analyses and calculations are duplicated or verified. The scope and depth of the review are focused on aspects or parameters of the site profile that would be particularly influential in deriving dose reconstructions, bridging uncertainties, or correcting technical inaccuracies. This review does not explicitly address the issue of radiation exposures to construction, clean-up and decommissioning workers, as they are not addressed in the TBDs.

The six TBDs serve as site-specific guidance documents used in support of dose reconstructions. These site profiles provide the health physicists who conduct dose reconstructions on behalf of NIOSH with consistent general information and specifications to support their individual dose reconstructions. This report was prepared by SC&A to provide the Advisory Board with an evaluation of whether and how the TBDs can support dose reconstruction decisions. The criteria

for evaluation include whether the TBDs provide a basis for scientifically supportable dose reconstruction in a manner that is adequate, complete, efficient, and claimant favorable. Specifically, these criteria were viewed from the lens of whether dose reconstructions based on the TBDs would provide for robust compensation decisions.

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

2.2 REVIEW APPROACH

SC&A's review of the TBDs and supporting documentation concentrated on determining the comprehensiveness of data collected by NIOSH, the adequacy of existing ORNL personnel and environmental monitoring data, and the evaluation of key dose reconstruction assumptions.

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) Vertical Issues and Secondary Issues
(6) Overall Adequacy of the ORNL 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. Issues can also be designated as Secondary Issues if they simply raise questions, which, if addressed, would further improve the TBDs and may possibly reveal deficiencies that will need to be addressed in future revisions of the TBDs.

Many of the issues that surfaced in the report correspond to more than one of the major objectives (i.e., strengths, completeness of data, technical accuracy, consistency among site profiles, and regulatory compliance). Section 6.0 provides in summary form a list of the issues, and to which objective the particular issue applies. Attachment 5 provides a more in-depth analysis of the consistency between site profiles.

In many ways, the TBDs have done a successful job in addressing a series of technical challenges. In other areas, the TBDs exhibit shortcomings that may influence some dose reconstructions in a substantial manner. Major issue areas include the following:

- Insufficient data for early worker dose reconstructions
- Inadequate consideration of missed dose from secondary radionuclides and radionuclide impurities
- Occupational exposure to radon is not fully addressed in the TBDs
- Insufficient characterization of the monitored workforce for beta/gamma and neutron monitoring
- Underestimation of neutron dose when using NTA file and in developing n-p ratios where the initial photon dose is not well characterized
- Lack of external dose assignment methodology for unmonitored workers
- Incomplete evaluation of medical x-ray exposures, especially in the early years
- Inadequate validation of source data used in dose reconstruction
- Concerns with reported deficiencies of air monitoring sampler locations at the site

SC&A believes that these important issues need to be effectively dealt with in any upcoming revisions to the ORNL site profile TBDs in order that more claimant-favorable dose reconstructions can be effectively conducted in areas where these data gaps exist.

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 and evaluated 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 ORNL Site Profile and supporting TIBs; however, items identified in this report may be applied to other facilities, especially facilities with similar source terms and exposure conditions. The review identifies a number of issues and discusses the degree to which the site profile fulfills the review objectives delineated in SC&A's site profile review procedure.

3.1 OBJECTIVES

SC&A reviewed and evaluated 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

This objective 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 it 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 captured at ORNL as a part of their records retrieval effort, and publicly available records.

3.1.2 Objective 2: Technical Accuracy

This objective 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 ORNL. The goal of this objective is to first analyze the data according to sound scientific principles, and then to evaluate this information in the context of compensation. 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

Objective 3 requires SC&A to determine whether the data and guidance presented in the site profile are sufficiently detailed and complete to conduct dose reconstruction, and whether a defensible approach has been developed in the absence of data. In addition, this objective requires SC&A to assess the credibility of the data used for dose reconstruction. The adequacy of the data identifies gaps in the facility data that may influence the outcome of the dose reconstruction process. For example, if a site did not monitor all workers exposed to neutrons who should have been monitored, this would be considered a gap and, thus, an inadequacy in the data.

3.1.4 Objective 4: Consistency among Site Profiles

This objective requires SC&A to identify common elements within site profiles completed or reviewed to date, as appropriate. In order to accomplish this objective, the ORNL TBD was compared to several of the sites already reviewed by SC&A. A detailed analysis of this review is provided in Attachment 5.

3.1.5 Objective 5: Regulatory Compliance

The Regulatory Compliance requires SC&A to evaluate the degree to which the site profile complies with stated policy and directives contained in 42 CFR Part 82. In addition, SC&A evaluated the TBD for adherence to general quality assurance policies and procedures utilized for the performance of dose reconstructions. 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 probability of causation (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 that results in a POC greater than 50%. For this reason, dose reconstructions under 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: This category adopts the “worst-case” assumptions in dose reconstruction in order to derive maximal or highly improbable dose assignments. For example, a worst-case assumption may place a worker at a given work location 24 hours per day and 365 days per year.

The use of such maximized (or upper-bound) values, however, is limited to those instances where the resultant maximized doses yield POC values below 50%, which are not compensated. For this second category, the dose reconstructor needs only to ensure that all potential internal and external exposure pathways have been considered.

The obvious benefit of "worst-case" assumptions and the use of maximized doses in dose reconstruction is efficiency, which 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: This represents the most complex and challenging dose reconstruction category. It consists 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 "reasonable," 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.]

In order to achieve the five objectives described above, SC&A reviewed each of the six TBDs, their supplemental attachments, and TIBs, giving due consideration to the three categories of dose reconstructions that the site profile is intended to support. The six ORNL TBDs provide well-organized information for the dose reconstructor when adequate data were available to do that comprehensively.

ORAUT-TKBS-0012-1, Rev. 00, *Technical Basis Document for Oak Ridge National Laboratory – Introduction* (Burns 2004a), explains the purpose and the scope of the site profile. SC&A was attentive to this section, because it 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 to the dose reconstructors 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. As will be discussed later in this report, NIOSH may want to include additional qualifying information in the introduction to this and other site profiles describing the dose reconstruction issues that are not explicitly addressed by a given site profile.

ORAUT-TKBS-0012-2, Rev. 01, *Technical Basis Document for Oak Ridge National Laboratory – Site Description* (Fleming 2006b), is an extremely important document, because it provides a description of the facilities, processes, and historical information that serve as the underpinning for subsequent ORNL TBDs.

ORAUT-TKBS-0012-3, Rev. 01 PC-1, *Technical Basis Document for Oak Ridge National Laboratory – Occupational Medical Dose* (Fleming 2006a), provides an overview of the sources, types of exposure, and the frequency of exams that workers potentially received.

ORAUT-TKBS-0012-4, Rev. 00, *Technical Basis Document for Oak Ridge National Laboratory – Occupational Environmental Dose* (Burns 2004b), provides background information and guidance to dose reconstructors for reconstructing the doses to unmonitored workers outside of the facilities at the site who may have been exposed to routine and episodic (accidental) airborne emissions from these facilities.

ORAUT-TKBS-0012-5, Rev. 00 PC-1, *Technical Basis Document for Oak Ridge National Laboratory – Occupational Internal Dose* (Bollenbacher et al. 2006), presents background information and guidance to dose reconstructors for deriving occupational internal doses to workers.

ORAUT-TKBS-0012-6, Rev. 00, *Technical Basis Document for Oak Ridge National Laboratory – Occupational External Dose* (Burns and Mohrbacher 2004), presents background information and guidance to dose reconstructors for deriving occupational external doses to workers.

Site expert interviews were conducted from February 22– March 3, 2006, in Oak Ridge, Tennessee, with former and current ORNL employees; Bechtel-Jacobs, Inc., employees; and Department of Energy–Oak Ridge Operations Office oversight personnel. The purpose of these interviews was to receive first-hand accounts of past radiological control and personnel monitoring practices at ORNL, and better understand how operations were conducted. Interviewees were selected to represent a reasonable cross-section of production areas and job categories. References to specific site experts have been omitted for privacy reasons. The individuals were given the opportunity to review their interview summary for accuracy. This is an important safeguard against missing key issues or misinterpreting some vital piece of information. To ensure that classified information had not been included in the interview notes,

the notes were reviewed by a classification officer prior to release to SC&A. The compilation of all site expert interviews is provided in Attachment 2.

In accordance with SC&A's site profile review procedures, SC&A performed an initial review of the six TBDs, their supporting documentation, and the two TIBs directly related to the ORNL site. SC&A submitted written questions to NIOSH pertaining to the ORNL Site Profile on August 1, 2006. NIOSH/ORAU provided written responses to these questions on August 25, 2006, prior to a conference call with SC&A. The questions and responses are provided in Attachment 3.

A conference call was held on September 6, 2006, with NIOSH/ORAU to allow them to provide clarifications and to explain the approaches employed in the site profile TBDs. A summary of this conference call is provided in Attachment 4.

An extensive comparison was done between the methodologies used in the ORNL TBD and other TBDs reviewed to date to determine environmental, internal, and external doses. This comparison focused on the methodologies and assumptions associated with dose reconstruction and resultant values used to obtain a POC. A detailed analysis is provided in Attachment 5.

Information provided in writing and as a part of the conference call with NIOSH was evaluated against the preliminary findings to finalize the vertical issues[1] addressed in the audit report. There are two levels of detailed review for this report. First, SC&A topical expert members review the report internally. This is then followed by what is referred to as the expanded review cycle, which will consist of a review of this draft by the Advisory Board and NIOSH. The first one of these has been completed.

A matrix containing the summary of findings is prepared by SC&A and released either simultaneously or shortly after the issuance of the review. After the Advisory Board and NIOSH have an opportunity to review this draft, a Working Group is formed by the Advisory Board to track issues identified within the review to their conclusion. NIOSH/ORAU is allowed to respond to the findings. In turn, SC&A is provided with the responses and evaluates them prior to meeting in person with the Working Group. During these Working Group meetings, both parties may decide the item has been resolved and is closed, or that additional action and/or clarification is needed. This process continues until all issues have been resolved. Reviews are also published on the NIOSH Web site and discussed at the next Advisory Board meeting.

Finally, it is important to note that SC&A's review of the six TBDs and their supporting TIBs is not exhaustive. 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.

[1] The term "vertical issues" refers to specific issues identified during our review, which were identified as requiring more in-depth analysis due to their potential to have a significant impact on dose reconstruction.

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 that claims can be processed in a timely manner. With this perspective in mind, we identified a number of strengths in the ORNL site TBDs. These strengths are described in the following sections.

4.1 COMPLETENESS OF DATA

In an effort to comprehensively address the range of facilities and processes at ORNL, NIOSH effectively compiled facility-specific information on major facilities and processes. Descriptions were provided for 78 facilities and 6 major processes (e.g., accelerators, reactors). A comprehensive and effective overview of key operations, their location, and dates of operation is also provided in the site profile. SC&A considers this an important start in providing background information for dose reconstructors. In fact, the ORNL Site Description TBD underwent a substantial rewrite during the course of the review. In site expert interviews conducted by SC&A, workers mentioned several facilities that were not included in Revision 0 of the site description. Revision 1 of the site description captured these facilities. This not only provides a more complete document, but shows workers they are being heard.

In developing the site profile, NIOSH/ORAU drew upon information contained in 226 reports cited in the reference sections. Process information was drawn from the Oak Ridge Dose Reconstruction project, historical program overviews, technical documents, and individuals currently or formerly involved in the Radiological Control group at ORNL. NIOSH/ORAU met with the ORNL Labor and Trades Council on November 8, 2004, in order to identify worker concerns and discuss the TBDs. This interaction has helped to provide valuable insight into site operations and processes. In addition, the issuances of several TIBs reflect ongoing efforts by NIOSH to continually improve guidance provided to dose reconstructors.

4.2 ADEQUACY OF DATA

The TBDs benefited from having access to information and data that were compiled as a part of the ORNL programs, as follows:

(1) Radiological control personnel have implemented improved procedures and technologies over time to reduce radiation dose to workers, and have improved personnel monitoring programs.

(2) Historical documentation of the Radiological Control program, including research activities, is well documented.

(3) ORNL implemented environmental monitoring, including stack monitoring, in-perimeter monitoring, offsite monitoring, and ambient external exposure monitoring.

(4) Starting in 1951, dosimeters were coupled with security badges, which helped ensure all workers were monitored for external radiation.

A good breakdown of the various site locations and activities as a function of time was provided. Dosimetry methods used for beta, photon, and neutron dose monitoring were described separately, and also as a function of time and technology changes. Some prescribed health physics monitoring procedures and record-keeping methods were described, along with the logbooks containing this information. ORNL has been fortunate to have noted scientists and research and development (R&D) facilities to address radiation and health physics problems throughout its years of operations.

The Occupational Medical Dose TBD (Fleming, 2006a) outlines the operating parameters and assumptions used in the development of x-ray dose in Table 3-3 (pg. 18). This summary is very helpful in succinctly presenting information to the dose reconstructor.

Site experts commented that the Occupational Environmental Dose TBD (Burns 2004b) appears to have utilized the correct references for evaluating the historical program.

4.3 TECHNICAL ACCURACY/CLAIMANT FAVORABILITY

The Occupational External Dose TBD (Burns and Mohrbacher 2004) was reviewed, and several areas of strengths were identified that will be useful in performing/evaluation dose reconstructions:

- Useful information concerning beta-gamma fields was provided (pp. 22–23).
- Information concerning many workplace neutron and photon radiation fields characterized in 1989–1991 was provided (pp. 23–44).
- Thermoluminescent Dosimeter (TLD) neutron and gamma dose data for 1990–2004 for numerous facilities and work groups was provided (pp. 44–60).
- Attachments 6A–6F provide a good summary of beta-gamma and neutron characterization and adjustment factors that is helpful in performing dose reconstructions without having to search through the complete TBD.

The Occupational External Dose TBD (Burns and Mohrbacher 2004) is fairly well written, and easy to follow. It incorporates a number of essential elements (informative table of contents, chronological flow of information, summary tables, etc.) sometimes only found in later revisions of TBDs.

The Occupational Internal Dose TBD (Bollenbacher et al. 2006) provides a good description of the in-vivo and in-vitro monitoring history at ORNL. There is a concerted effort to independently evaluate minimum detectable concentrations (MDCs) for bioassay techniques based on analytical records. The TBD recognizes the shortcomings in the in-vivo monitoring

program and takes this into consideration. NIOSH/ORAU has concurred with SC&A that potential radon, tritide, and americium exposure from plutonium mixtures requires further investigation.

4.4 CONSISTENCY AMONG SITE PROFILES

Dose assignments to Y-12 Plant workers and ORNL workers located at Y-12 is not equivalent for the same or similar operations. Consideration should be given to the radiological conditions at this location and how they may impact dose.

The implementation of ORAUT-OTIB-0006, *Dose Reconstruction for Occupationally Related Diagnostic X-Ray Procedures*, Revision 2 (Kathren 2003), has provided a great deal of consistency between different site profile assumptions. Incorporation of Revision 3 PC-1 (Kathren and Shockley 2005) of this document would provide further consistency among site profiles. The NIOSH/ORAU team is moving in the right direction to obtain consistency in most assumptions for occupational medical exposure.

4.5 REGULATORY COMPLIANCE

The TBDs' use of personnel monitoring data and environmental monitoring data to determine dose is consistent with the requirements outlined in 42 CFR Part 82, as follows:

- Where in-vivo and in-vitro analyses are available, this information is provided for use in determination of internal dose.

- Where routine beta/gamma and neutron dosimeters are available and adequate, this information is provided for use in determination of external exposure.

- Where environmental measurements are available, these data are used as the basis for environmental dose.

5.0 VERTICAL ISSUES

SC&A has developed a list of key issues regarding the ORNL Site Profile. These issues relate to each of the five objectives defined in SC&A's review procedures (SC&A 2004). Some issues are related to a particular objective, while others cover several objectives. Many of the issues raised below are applicable to other DOE and Atomic Weapons Employer sites, and should be considered in the preparation and revision of other site profiles.

5.1 ISSUE 1: INCOMPLETE DOSE DATA FOR THE EARLIER YEARS

Information available for dose reconstruction in the early years is limited, inadequate, or in some cases, not available. External monitoring for the years 1943–1944 was limited to pocket ionization chambers (PICs). Neutron dosimetry was not available until 1949 when ORNL implemented NTA film. The lack of complete photon dosimetry data in the early days brings into question the use of n-p ratios for the assignment of neutron doses. Bioassay processes were not routinely available prior to 1949, and the first bioassay techniques were limited to Sr-90 and plutonium. Reactor, accelerator, and chemical separations operations began at ORNL prior to the implementation of the routine bioassay program. Prior to this time, the reliance was on air sampling and contamination control, which forms the basis for dose reconstruction from 1943–1947. The production and handling of other radionuclides such as Ba/La-140, radium, and other alpha and beta emitters, preceded many of the bioassay techniques for these sources. Overall, the Health Physics group of the 1940s focused their efforts on keeping individuals within the defined tolerances of the time, rather than eliminating internal exposure all together.

The Graphite Reactor, built to produce plutonium for the weapons program, went critical on November 4, 1943. Process separations at the plutonium-separation pilot plant began in December 1943, with uranium irradiated at an accelerator at Washington University. The first shipment of separated plutonium was sent from Oak Ridge to Los Alamos in February 1944 (Johnson and Schaffer 1994). In 1944, Los Alamos requested that ORNL produce 100 Ci of Ba-140, which decayed to La-140, for use in weapons development. In 1944, the Graphite Reactor was used to irradiate Bismuth-210 slugs for the production of Po-210 used in initiators. Other early ORNL missions were to perform R&D related to nuclear fission, nuclear reactors, and the plutonium-separation process. The Chemistry Division supported not only the plutonium-separation operations, but preparation and use of radionuclide tracers (e.g., tritium, radioactive phosphorus, and radioactive antimony). Analytical techniques were developed for the identification of fission products. The Health Division conducted animal experiments to evaluate radiation effects. Around mid-1945, the laboratory began to separate U-233 from irradiated thorium. In August 1946, radionuclides produced at ORNL became available to those outside the Manhattan Project (Quist 2000).

5.1.1 Internal

Table 5A-2, page 39, of the Occupational Internal Dose TBD (Bollenbacher et al. 2006) provides minimum detectable activity (MDA) values that have been determined for gross alpha, gross beta, and 16 radionuclides found in urinalysis sampling, and gross alpha and 4 radionuclides

found in fecal sampling. A method for identifying workers and assigning missed dose is lacking in this document for those potentially exposed to all the assorted radionuclides, for which MDAs have been determined (Table 5A-2, page 39). Likewise, for all the other radionuclides, such as those produced by the ORNL Isotopes Production Group at Y-12, a method is lacking for assigning a missed dose. This issue needs to be addressed regarding this group of workers who received considerable attention during the Y-12 Special Exposure Cohort (SEC) petition review.

NIOSH has concluded that the radionuclides likely to produce a measurable internal dose were uranium, transuranics, activation products, and fission products. As mentioned in the introduction to this section, there was potential exposure to uranium, plutonium, fission products, Ba/La-140, Po-210, tritium, U-233, and thorium starting in the 1940s. Table 5-9 provides in-vitro MDAs for 1947 to 1989. Exposures to even those radionuclides of concern, as defined by NIOSH, occurred prior to 1947 (Bollenbacher et al. 2006, pg. 16). Furthermore, isotope-specific in-vitro analysis did not become routine until 1989, with the radionuclide being determined in some cases based on process knowledge. Page 11 of the ORNL Occupational Internal Dose TBD ORAUT-TKBS-0012-5 (Bollenbacher et al. 2006) notes the following:

> *…urine samples were collected in the early years of the bioassay program based on the area health physicist's knowledge of field conditions (e.g., known spills/incidents, air and contamination sample results, etc.). This practice of scheduling did not utilize a specified sampling frequency.*

On page 21, the TBD further notes the following:

> *Although several located documents stated that baseline and specified monitoring frequencies were utilized to make in-vivo measurements, Berger (2003) and McLaughlin (2004) indicated that a full in-vivo monitoring program did not exist at ORNL until approximately 1994, when site internal dosimetrists became responsible for identifying personnel for counting.*

This practice for determining sampling for both in-vitro and in-vivo monitoring throughout the history of the site through the 1980s or even 1990s raises a serious question regarding unmonitored workers with potential for uptakes. The issue is further exacerbated in Table 5-3 on page 11, where it states that these sampling frequencies **should** be followed; however, the text notes (Section 5.1.4.1) that these may not have been followed. (Emphasis added.)

With the diversity of radionuclides handled by ORNL (including operations at Y-12), it is uncertain how NIOSH/ORAU has determined that radionuclides other than transuranics, activation products, fission products, and uranium are the only significant dose contributors. It is also unclear what the TBD means by "activation product." Are these exclusively those radionuclides created by activation of material in reactors, or does it include accelerator material? A screening analysis should be completed for all radionuclides mentioned in the Site Description TBD to ensure there was a method for detection of this radionuclide while it was handled, or that the dose consequences for the radionuclide are trivial.

5.1.2 External

With the operation of a reactor and the handling of irradiated fuel, the potential existed not only for beta/gamma exposure, but for neutron exposure as well. The Occupational External Dose TBD states the following (Burns and Mohrbacher 2004):

> *Beginning in October 1943, ORNL issued paired pocket dosimeters to workers assigned to duties in the restricted areas associated with Graphite Reactor operations. Pocket dosimeters were used in pairs because of reliability issues associated with early designs. ORNL issued two dosimeters so there was a back up if one of them failed, went off the scale, or was otherwise unusable. An individual received these dual dosimeters if restricted area entries were likely more than three times per week. If entry into restricted areas was likely to be less than three times per week or on a random basis, workers received dosimeters for each entry.*

The TBD further indicates that experimental dosimeters were worn by some personnel for the first half of 1944 (Burns and Mohrbacher 2004). The Occupational External TBD does not provide instruction on how to assign dose for 1943 and 1944 to workers who may have only worn PICs. The error associated with these units will differ from that of a film badge and should be considered. Co-worker doses are provided in OTIB-0021 (Kennedy 2005) for this period; however, the Occupational External Dose TBD makes the following statement (Burns and Mohrbacher 2004):

> *Film dosimeter readings (results) encountered in ORNL personnel monitoring histories before June 25, 1944, could be unreliable because the use of dosimeters during this time was experimental (Hart 1966).*

Information on how this experimental data is being used in both individual and co-worker doses is minimal. There is no information on which portion of the population wore these dosimeters, and if they were representative of the population. The policy for monitoring from June 1944 through November 1951 was based on the number of entries an individual made into a radiation area, or whether they worked with radioactive material. Routine dosimeters were assigned to those who frequented radiation areas, while trip dosimeters were assigned to individuals who intermittently visited radiation areas. The uncertainty related to the photon monitoring system does not instill confidence in the reconstruction of dose for the early years.

The Occupational External Dose TBD indicates that neutron monitoring was formally introduced in 1949 (Burns and Mohrbacher 2004):

> *Neutron personnel monitoring using NTA film was formally introduced at ORNL around 1949. However, NTA film was apparently used on a limited basis to supplement field measurements as early as February 1945 (Wirth, Morgan, and Curtis 1945)…. Once it became available, NTA film was used in all assigned*

> *employee badges and exchanged on a weekly basis. However, the film was not processed unless the health physicist recommended it.*

Bradley (1945) indicated that routine monitoring of 105 personnel was conducted by inserting a special film in the regular beta/gamma meter. Neutron monitoring was initially determined by the Health Physics Division Director, as indicated by Ledbetter (1948) and later by Health Physicists in the field.

NIOSH uses primarily n-p ratios to determine the external dose. Currently, they have developed n-p ratios from neutron dosimetry results for 1999–2004. Neutron ratios vary substantially, depending on how they are generated and what shielding is present. Radiological conditions today are significantly different from those from the 1940s in terms of implementation of engineering and administrative controls to limit dose. ORNL currently has a research mission whereas in the 1940s, the focus was on production of material for the weapons program. NIOSH needs to further explain how the application of n-p ratios from the present time is representative of those from the 1940s. Secondly, the uncertainty related to the photon monitoring system does not instill confidence in the reconstruction of dose for the early years.

The Laboratory was involved in activities that led to significant beta exposures. For example, Morgan and Peterson (1999) state the following:

> *Skin erythema from beta radiation represented a special early concern at X-10 because some employees refused to wear heavy leaded gloves and even handled uranium slugs with their bare hands when we weren't looking.*

Pocket ionization chambers are designed to measure photon exposure, rather than beta exposure. For those years when PICs were the exclusive monitoring system, there was an absence of personnel beta monitoring. Potential skin exposure from environmental releases was also a concern with early particle emissions that deposited on the ground and, in some cases, on personnel.

> *The other serious incident in the very early period involved the release of small uranium particles that contained plutonium and fission products. These "hot" particles from a chemical separation operation would fall all over the laboratory areas (Morgan and Peterson 1999).*

In the conference call held with NIOSH, it was indicated that these particles would be measured by the ambient air monitoring system (see Attachment 4). The concern here is not limited to inhalation, but also localized external exposure and exposure to unmonitored workers. Some consideration should be given to this route of exposure in terms of internal as well as external exposures.

The University of Chicago was the first operating contractor at ORNL. As a result, many of those involved with work at the Metallurgical Laboratory relocated to Oak Ridge to assist in getting ORNL operational. For those individuals who terminated their employment prior to the

end of the University of Chicago contract, personal records were shipped back to the University of Chicago (Deal and Hart 1949).

5.1.3 Air Sampling

As discussed above, there is an absence of bioassay data for the period 1943–1947. NIOSH has located 1,483 air-monitoring records ranging from 1944 to 1947. Presumably, these 1,483 ORNL specific air samples have been used to determine dose to unmonitored workers. The methodology presented in the TBD requires some clarification. For example, if the ORNL samples were used, what was the type and location of the sample in relation to the individual exposed? The TBD references OTIB-0018, *Internal Dose Overestimates for Facilities with Air Sampling Programs* (Brackett and Bihl 2005); however, it is unclear whether the OTIB is being used in the analysis. The sensitivity of survey instruments, locations of the air sampling, and air flow studies of the buildings were not considered. These factors would impact the accuracy of the air concentration data.

In 1990, the Tiger Team evaluated all elements of the radiation protection program, including the air monitoring program. The following statement was made with respect to air sampler placement (DOE 1990):

> *A thorough study of air flow patterns in ORNL facilities has been completed. This study indicates that the placement and air sampling number is inadequate. It will provide the basis for decisions on the location and type of additional air samplers and air monitors to meet the requirements.*

If the air samples were not appropriately placed in 1990, this leads to questions on whether they were appropriately placed in the 1940s. This could significantly affect the result. Several technical studies, including the recent 2003 Y-12 study, *Practical Use of Personal Air Sampling (PAS) Data in the Internal Dosimetry Program at the Y-12 National Security Complex* (Snapp 2003), and Nuclear Regulatory Commission's NUREG-1400, *Air Sampling in the Workplace* (Hickey et al. 1993), demonstrate that using air concentration data would lead to underestimating the worker intakes and subsequently the internal exposures.

With the unknowns and shortcomings associated with the use of airborne concentration data for estimating missed dose, further evaluation should be provided to make sure this approach is bounding for unmonitored acute and chronic intakes.

5.2 ISSUE 2: INADEQUATE CONSIDERATION OF MISSED DOSE FROM OTHER RADIONUCLIDES

Although the Occupational Internal Dose TBD, ORAUT-TKBS-0012-5 (Bollenbacher et al. 2006), acknowledges their existence, the TBD does not adequately address potential doses from secondary or so-called "exotic" radionuclides. The focus of the TBD is on "radionuclides likely to produce a measurable internal dose," including uranium, activation products, fission products, and transuranics. Numerous radionuclides were handled at ORNL ranging in quantities from

fractions of a gram to kilograms. The amounts of particular radionuclides handled changed over time and has changed with ORNL's mission. The basis of dose assignment for monitored workers is based on in-vitro bioassay data. For unmonitored workers with the potential for exposure, a co-worker dose is assigned. Radionuclides for which co-worker dose was assigned included strontium, uranium, plutonium, Am-241, Cs-137, Ce-144, and Ru-106 (Kennedy 2005). Although the TBD presents MDAs for a number of radionuclides, it is unclear what this data is used for, and whether it is used to estimate dose.

Both R&D and production operations have contributed to the extensive and diverse list of radionuclides historically present at ORNL. Reactors have been used to irradiate elements. The long-term operations and R&D activities at ORNL provided constant opportunities for workers to come in contact with radionuclides spanning the periodic table. Table 5.1 shows the radionuclides handled by ORNL that have not been considered in the missed dose calculations or co-worker analyses. The radionuclides have been limited to those with a half-life greater than 1 day. Those radionuclides with half-lives less than 1 day have been excluded. The first date the material was identified in the reviewed literature and the year from the earliest bioassay have been provided.

Table 5-1: Radionuclides Handled at ORNL without Consideration in the Technical Basis Document

Radionuclide	Predominant Decay Mode	Half-Life	Radionuclide	Predominant Decay Mode	Half-life
Am-243	Alpha	7,370 y	Mn-52	EC/Gamma	5.591 d
As-74	Beta/Gamma	17.77 d	Mn-54	EC/Gamma	312.12 d
As-76	Beta/Gamma	1.07788 d	Mo-99	Beta/Gamma	65.94 h
As-77	Beta/Gamma	38.83 h	Na-24	Beta/Gamma	14.959 h
Au-198	Beta/Gamma	2.6951 d	Nb-95	Beta/Gamma	34.9749 d
Ba/La-140	Beta/Gamma	12.752 d/1.6781d	Ni-63	Beta	100.1 y
Ba-133	EC	10.52 y	Ni-65	Beta/Gamma	2.5171 h
Bi-207	EC	31.5499 y	Np-234	EC/Gamma	4.4 d
Bi-210	Beta, no gamma	5.013 d	Os-185	EC/Gamma	93.5999 d
Bk-249	Beta, no gamma	320 d	Os-191	Beta/Gamma	15.4 d
Br-82	Beta/Gamma	35.2999 h	Os-193	Beta/Gamma	30.11 h
C-14	Beta	5,730 y	P-32	Beta	14.26 d
Ca-41	EC	103,000 y	P-33	Beta	25.34 d
Ca-45	Beta	162.61 d	Pa-231	Alpha/Gamma	32,760 y
Cd-109	EC	461.3999 d	Pa-233	Beta/Gamma	26.9669 d
Cd-115	Beta/Gamma	53.4599 h	Pb-210	Beta/Gamma	22.2999 y
Cf-249	Alpha	500 y	Pd-103	EC/Gamma	16.9909 d
Cf-252	Alpha	2.2 y	Pd-107	Beta	6,500,000 y
Cl-36	Beta/Gamma	301,000 y	Ra-228	Beta/Gamma	5.75 y
Cm-242	Alpha	162.8 d	Rb-86	Beta/Gamma	18.631 d
Cm-246	Alpha	4,000 y	Re-186	Beta/Gamma	3.7183 d
Co-56/57	EC/beta/gamma	77.233 d/271.7399 d	Ru-103	Beta/Gamma	39.2599 d
Co-58	EC/beta/gamma	70.86 d	S-35	Beta	87.2599 d
Co-60	Beta/gamma	5.2714 y	Sb-124	Beta/Gamma	60.2 d

Table 5-1: Radionuclides Handled at ORNL without Consideration in the Technical Basis Document

Radionuclide	Predominant Decay Mode	Half-Life	Radionuclide	Predominant Decay Mode	Half-life
Cr-51	EC/Gamma	27.7024 d	Sb-125	Beta/Gamma	2.7585 y
Cs-134	Beta/Gamma	2.0648 y	Sc-46	Beta/Gamma	83.8099 d
Cu-67	Beta/Gamma	61.83 h	Se-75	EC/Gamma	119.79 d
Dy/Ho-166	Beta/Gamma	81.5999 h/26.7999 h	Se-79	Beta	1,100,000 y
Es-253	Alpha	20.4699 d	Sm-151	Beta/Gamma	90 y
Es-254	Alpha	275.7 d	Sn-113	EC/Gamma	115.09 d
Eu-152	Beta/Alpha	13.537 y	Ta-182	Beta/Gamma	114.43 d
Eu-152	Beta/Alpha	9.3115 h	Tc-99	Beta	211,100 y
Eu-154	Beta/Alpha	8.593 y	Th-228	Alpha/Gamma	1.919 y
Eu-155	Beta, no gamma	4.761 y	Th-229	Alpha/Gamma	7,340 y
Fe-55	EC	2.73 y	Th-230	Alpha/Gamma	75,380 y
Fe-59	Beta/Gamma	44.5029 d	Tl-201	EC/Gamma	72.912 h
Ga-67	EC/Gamma	3.2612 d	Tl-204	Beta/Alpha	3.78 y
Gd-153	EC/Gamma	240.3999 d	Tm-170	Beta/Alpha	128.6 d
Ge-68	EC	270.82 d	W-185	Beta/Gamma	75.0999 d
Hf-181	Beta/Gamma	42.3899 d	W-188	Beta/Gamma	69.4 d
Hg-203	Beta/Gamma	46.612 d	Xe-133	Beta/Gamma	5.243 d
I-125	EC/Gamma	59.4 d	Y-88	EC/Positron/Gamma	106.65 d
I-129	Beta/Gamma	1.57 E+7 y	Y-90	Beta	64.0999 h
Ir-192	Beta/Alpha	73.827 d	Zn-65	EC/Gamma/Positron	244.2599 d
K-42	Beta/Gamma	12.36 h	Zr-93	Beta	1,530,000 y
Kr-85	Beta/Gamma	10.756 y	Zr-95	Beta/Gamma	64.0199 y

EC = Electron Capture

The main campus of ORNL housed two major accelerators with several smaller accelerators distributed throughout divisions (e.g., Van de Graaff Accelerator). The Oak Ridge Electron Linear Accelerator (ORELA) facility consisted of a 180-MeV electron accelerator, neutron-producing targets, and evacuated flight tubes. The Oak Ridge Isochronous Cyclotron (ORIC) began operation in 1962. It originally supported a program of light-ion and heavy-ion nuclear physics until 1980. In 1980, this accelerator began operation as a beam injection for a 25-MV tandem electrostatic accelerator. The Holified Heavy Ion Research Facility (HHIRF), later known as the Holified Radioactive Ion Beam Facility, produces beams of short-lived nuclei for studies of exotic nuclei and astrophysics. These accelerators were involved in producing or analyzing radionuclides of all types (e.g., Ge-62, F-18). In some cases, the radionuclide was discovered at the accelerator (e.g., Xe-109, Te-105). The High Flux Isotope Reactor (HFIR) produced Ir-92, Co-60, californium-252, and other transuranium isotopes for research, industrial, and medical applications (Johnson and Schaffer 1994; www.phy.ornl.gov, Attachment 2). The isotope production areas were involved with the processing of secondary radionuclides, including the following (Fleming 2006b, pp. 33–38):

- I-131 processing facility and the separation facility for Pm-147
- Xe-133 facility to produce Xe-133, I-131, and Mo-99

- Source fabrication (e.g., curium, Co-60, Sr-90)
- Isotope separations
- Radioactive lanthanum separation

Several ORNL operations were conducted at the Y-12 Plant. The operations at Y-12 included the following (Fleming 2006b, pp. 40–42):

- R&D by the Biology Division (Buildings 9207, 9208, 9210, 9211, 9220, 9224, 9743, 9767-3, 9767-5, and 9982)
- Stable and radioactive isotope separations at the Calutron (Building 9204-3)
- Critical Experiments Facility (CEF) (Building 9213)
- Fusion Research Division (Building 9201-2)
- Engineering Technology Division (Buildings 9201-3, 9204-1)
- Cyclotron Operations (86-inch, 22-inch, 63-inch) (Building 9201-2)
- 5 MeV Van de Graaff Accelerator (Building 9202-2).

A substantial variety of radionuclides was produced or handled in the Y-12 Plant calutron/cyclotron area. The 86-inch cyclotron was used to investigate the radiation effects on material, to produce radio-isotopes, and for experiments in basic physics. Operations with this particular cyclotron started in 1950 (Livingston and Boch 1952, pp. 7–8):

> *The 86-inch cyclotron was constructed as a fixed-frequency cyclotron to produce 25 MeV protons. The first proton beam was observed from the cyclotron on November 11, 1950. Continued development has resulted in improvements of the stability of operations and in larger proton currents.*

The 86-inch cyclotron was involved in angular-distribution measurements of neutrons from (p,n) reactions in targets; angular distribution measurements of fission fragments from proton-induced fission of U-233, U-235, U-238, Th-230, and Th-232; measurement of alpha-particle angular distributions from (proton, alpha) reactors; studies of the neutron-deficient isotopes of terbium; and completion of an extensive program of the measurement of activation cross sections. The compilation of the available data shows that isotopes produced included Be-7, Ba-133, Bi-210, F-18, Na-22, Mn-52, Mn-54, Fe-55, Co-56, Co-57, Zn-65, Ga-67, As-73, As-74, Y-88, V-49, Cr-51, Ge-68, Rb-84, Sr-85, Mo-93, Pd-103, I-123, Ce-135, Cs-137, Tm-165, W-181, Au-195, Pb-203, and Po-208 (Livingston 1954, Gillette et al. 1962). The Calutron at Y-12 Plant was used to separate stable isotopes as well as radioactive isotopes. Heavy elements separated at the Calutron include uranium, plutonium, neptunium, and americium (Gillette et al. 1962).

A discussion of exposure to or problems with radon or radon daughters was not included in the TBD. This has been a problem or issue at most DOE sites, and is noted as a concern in early documents at ORNL (Ferry 1944, a series of Memoranda to Col. Stafford L. Warren, March–June 1944) but is not addressed in the ORAUT-TKBS-0012-5 TBD (Bollenbacher et al. 2006).

This Memorandum to Col. Warren, dated March 2, 1944 (Ferry 1944), points out that air samples in warehouses where ore was stored contained Mz (Radon) concentrations as high as 6,700 microcuries/liter, which was 67.0 times tolerance. Col. Warren responded in a letter dated March 21, 1944, with 15 points regarding the issue and recommendations (Warren 1944). Upon Col. Warren's recommendations, a large number of exhaust fans were introduced into the warehouses to circulate and exhaust the radon concentrations. A letter to Col. Warren, dated June 13, 1944 (Tybout 1944), points out that even after fans were installed, one warehouse sample still was 26 times tolerance. It is a well-established fact that radon has been a problem even in enclosed areas without ore storage as a result of background buildup from natural soils and building materials. SC&A believes that the problems radon presents in monitoring and potential exposure should be addressed in the TBD.

There are over 2,000 radioanalytical results given in Table 5-1 for tritium. SC&A finds no discussion about whether any of the tritium at ORNL was in tritide form. In reviewing the *ORNL Internal Dosimetry Program Technical Basis Document, Revision 7*, December 21, 2005 (McLaughlin 2005), it appears that all tritium was assumed to be in elemental hydrogen or water vapor forms, HTO and T_2O. Two documents reviewed, *Methods and Procedures For Internal Radiation Dosimetry at ORNL*, January 1, 1969 (Gupton 1969), and *Recommended Procedures for Tritium*, August 1958 (Nielson 1958), also assumed these forms of tritium. None of the reviewed ORNL TBD documents appear to even make mention of possible tritides or metal tritide forms. It is SC&A's belief that this should be addressed as to whether there were no tritide or metal tritide forms present, or if only elemental and water forms of tritium existed at ORNL. Many other DOE sites have had tritides present. It should be clarified whether or not ORNL had such metal tritide exposure potential. This could influence the dose reconstruction process.

The Occupational Internal Dose TBD, ORAUT-TKBS-0012-5 (Bollenbacher et al. 2006), does not appear to address the issue of missed dose from americium. When plutonium mixtures are present, the absence of americium above detection levels should not preclude the calculation of dose from americium contribution to the mixture. Table 5-10 (Bollenbacher et al. 2006, pg. 17) includes Am-241 in the sequential analysis. However, americium should not be inferred as being absent without the presence of plutonium. SC&A does not see reference to the ingrowth of Am-241 into these mixtures and the issues it presents in in-vivo and in-vitro monitoring for internal dose reconstruction. The TBD seems to be silent with regard to this issue.

Section 5.2.3.1 on page 18 of the TBD (Bollenbacher et al. 2006) notes the following:

> *…monitoring of transplutonium elements was unable to differentiate between such nuclides as ^{241}Am and ^{244}Cm. The default radionuclide to use with measurements involving trivalent alpha actinides would be ^{241}Am. The detection sensitivity of transplutonium analysis technique is not well documented for samples processed before 1985.*

Considering the fact that Cm-244 was handled as a radionuclide, this approach would appear to be faulty and could lead to missed dose from curium, unless it can be proven that workers had no opportunity for exposure to both radionuclides.

These potential sources of exposure from secondary radionuclides are based on a limited SC&A review of ORNL operational history and available health physics files. Further research by NIOSH into these non-traditional radionuclides should be completed in any revision of the ORNL Site Profile to assure that their significance and dose contribution is fully addressed. The TBD should include when to assign dose from secondary radionuclide uptakes, and what default assumptions should be provided. Bioassay techniques should be evaluated for entire periods of potential exposure for effectiveness in detecting other radionuclides. Appropriate methods for internal monitoring were not always available for all years of potential exposure. Although the TBD (Bollenbacher et al. 2006) acknowledges the existence of non-traditional radionuclides, adequate direction is not provided on how and when to assess potential missed dose for them. The site profile is reliant on the existence of bioassay data or claimant interviews to ascertain potential exposure to secondary radionuclides. This puts the former worker, and particularly the survivor, at a disadvantage because of the lack of hazard identification and considerable secrecy. The TBD has not considered the possibility that due to secrecy, the energy employee may not have known what radionuclides were in the workplace. NIOSH/ORAU should base missed dose assignments on available data, technical reports, and other sources of information to ascertain potential exposure to secondary radionuclides.

5.3 ISSUE 3: PROBLEMS WITH NEUTRON DOSES

In view of several statements made in the Occupational External Dose TBD (Burns and Mohrbacher 2004), the use of NTA film to monitor neutron doses at ORNL raises several areas of concern. For example, page 23 of the TBD mentions that neutron energy spectra and neutron exposure data before the late 1980s is sparse, and that information is particularly lacking for many of the reactors that operated at ORNL early in its history. If n-p values are used instead of NTA dose records, these concerns are still valid, because using n-p values depends on a detailed knowledge of the gamma and neutron doses and neutron energy spectra at each work location as a function of time.

5.3.1 NTA Film Neutron Energy Threshold

The TBD acknowledges that NTA film would miss most neutrons below about 1 MeV and miss all neutrons below 0.5 MeV. The TBD also provides the fraction of dose above 0.5 MeV as a function of facility in Table 6F (pg. 82). However, it is not obvious that the dose reconstructor has sufficient detailed correction factor information and instructions available in the TBD to correct for the unmonitored neutron doses resulting from neutrons with less than 1 MeV of energy at the numerous facilities that produced neutron exposures through the years. The TBD does not provide information on how neutron dose reconstruction for facilities with all neutrons below the 500 keV cutoff will be handled at such facilities as the HFIR, the Graphite Reactor, the Radiochemical Engineering Development Center (REDC), and the Transuranium Decontamination Facility (TDF).

5.3.2 Neutron-to-Photon Ratios

Neutron-photon values are used to determine neutron doses instead of NTA film results. The validity of this process is highly dependent on the reliability of the photon dose data. This is especially important because the total dose is dependent on only one dose measurement, and there is no ability to cross-check the gamma and neutron doses. Additionally, at some time, the n-p value has to have been measured for each exposure situation and knowledge of the neutron energy spectra obtained. The Occupational External Dose TBD (Burns and Mohrbacher 2004, pg. 24) states that most neutron energy spectra, doses, and n-p values to be used in dose reconstruction were measured since 1989. There is no spectral data presented for the early years when NTA film was in use. The TBD also mentions that conditions at reactor, accelerator, and calibration facilities are not likely to change. This may be true for a power or even a production reactor, but may not be generally true for research reactors and accelerators. Values of n-p and knowledge of the associated neutron energy spectra used in dose reconstruction should originate from the working conditions during exposure, not from measurements that took place much later in time. Dose parameters measured 30–50 years after the doses were received may not be directly applicable to dose reconstruction. In light of these concerns, it would be relevant to address the following:

- Provide information on early n-p values and neutron spectra available to be used for neutron dose reconstruction.

- Provide information concerning differences and similarities between early and later n-p values and neutron spectra investigated to date.

- If early n-p values and neutron energies spectra are lacking, present justification for using later data.

5.3.3 Neutron Quality Factors

Several items in the Occupational External Dose TBD (Burns and Mohrbacher 2004) concerning neutron dose adjustments need clarification:

- The TBD (page 68) instructs the dose reconstructor to correct the recorded neutron dose to account for the difference between the neutron quality factors in NCRP-38 (NCRP 1971) and ICRP-60 (ICRP 1990). However, on page 69, it again recommends applying a factor of 2. This could confuse the dose reconstructor and the dose may get doubled twice.

- Attachment 6C, page 79, of the TBD lists n-p values measured during 1989–1991 in different facilities. The footnote indicates that the dose reconstructor should double the geometric means, minimum, and maximum to account for ICRP-60 radiation weighting factors. However, only neutron-to-gamma dose ratios are listed, not geometric means, etc. It is unclear if the dose reconstructor is to double the n-p values listed in this table when performing neutron dose reconstruction.

These items could lead to increasing the neutron dose more than is technically justified.

5.3.4 NTA Film Fading

The TBD makes no mention of NTA film track fading. Track fading can result in sufficient loss of dose data, especially for tracks resulting from lower-energy neutrons and/or in high humidity environments. Track fading from lower-energy neutrons has been observed as high as 56% per 2-week exchange at Mound Laboratory (Proctor and Alguitifan 2004). This area needs to be addressed to determine if the exposure conditions at ORNL warrant track-fading correction factors for NTA film when used for neutron dose reconstruction or in determining n-p values.

5.4 INFORMATION NEEDED CONCERNING EARLY DAY DOSE DATA AND SELECTION OF WORKERS FOR BADGING.

5.4.1 Dose Data for the Earlier Years

The Occupational External Dose TBD (Burns and Mohrbacher 2004) outlines the general beta/photon dosimetry techniques and dose reconstruction procedures for skin and penetrating doses. Attachment A of the TBD, pages 76–77, provides the recommended beta/gamma energy groups for the IREP program as a function of major work location at ORNL. Neutron adjustment factors are summarized in Attachments 6B–6F. However, the TBD only provides general information concerning worker monitoring and dose data. The TBD states on page 17 that some workers were badged with experimental film before June 1944, but that these records may not be reliable. Therefore, it would appear that there is not sufficient beta/photon dose data to allow dose reconstruction for workers during 1943–June 1944. In order to evaluate the sufficiency of dose data for these early years (1943–1960s), the TBD needs to provide the following:

(1) Information concerning:
- The total number of workers each year
- The number of workers monitored (and recorded) each year

(2) The number of workers monitored each year for:
- Beta/low-energy photon
- Photons
- Neutron

(3) Details concerning the doses recorded each year, such as:
- Minimum and maximum doses
- Median dose
- Percent of zeros and LOD recorded
- Meaning of blank entries

(4) Handling of abnormal readings:
- Black/unreadable films
- Lost, unreturned, damaged, contaminated badges
- Unexpectedly high readings

5.4.2 Selection of Workers for Badging

The Occupational External Dose TBD (Burns and Mohrbacher 2004) does not provide sufficient details concerning who was badged, and when, to ensure that workers were sufficiently monitored to allow for technically sound dose reconstruction. Table 6-2, page 16, of the TBD provides a list of the characteristics of dosimeters from 1944 to the present worn by *radiation* workers at ORNL, but does not describe what defined a radiation worker. The TBD (pp. 14–15) provides information on types, classes, color/dots, and usage of dosimeters, but no details concerning who was considered a radiation worker. Therefore, it is not known if the appropriate workers were monitored. On page 11 of the TBD, it states that NTA films were only read if the health physicist recommended it to be processed; this policy could lead to a false sense of being monitored, but the neutron dose went unrecorded on the worker's dose record. The TBD does not provide sufficient details to ensure that the workers that needed to be monitored were actually monitored and their doses recorded for claimant-favorable dose reconstruction. To evaluate the sufficiency of monitoring the TBD needs to address the following:

- Provide a definition of a radiation worker as used at ORNL
- Investigate what policies were used over the years to determine what workers were badged
- Determine how, and to what extent, these policies were enforced
- Determine if there were groups that may have been badged after the fact (i.e., the radiation hazard may have gone unrecognized in the beginning), especially in the early years
- Determine if the maximum exposed were badged, or if it was cohort/rotational/random badging
- If it is postulated that the maximum exposed were badged, provide information/data to support this fact

5.5 ISSUE 5: LACK OF DOSE ASSIGNMENT PROCEDURE FOR UNMONITORED WORKERS

The Occupational External Dose TBD (Burns and Mohrbacher 2004) does not provide a defined procedure to assign dose to unmonitored workers. Section 6.5.1 briefly mentions LODs, and provides a listing of the LOD and exchange frequency as a function of time (Table 6-24, pg. 69). However, this should only be applied to the dose missed by the dosimeter worn by a worker, not the dose missed because a worker was not badged. This applies to neutron as well as photon and beta doses. During these early years, an unmonitored worker could have received dose without management or the worker being fully aware of the hazards. The TBD needs to provide technically sound dose reconstruction procedures for assigning doses to unmonitored workers, especially in the early years (1943–1960s) when radiation hazards were not always recognized or effectively addressed. OTIB-0021 (Merwin 2004) was issued on December 29, 2004, after the Occupational External Dose TBD (Burns and Mohrbacher 2004, issued on August 11, 2004). OTIB-0021 contains some recommendations for maximum/minimum (not best-estimate) beta

and photon (not neutron) doses for 1943–1985. It is uncertain how co-worker data in Table 2 of OTIB-0021 can contain ORNL co-worker data for 1943 and 1944. The TBD seems to contradict this when it states on page 17 that film dosimeter readings (results) encountered in ORNL personnel monitoring histories before June 25, 1944, could be unreliable, because the use of dosimeters during this time was experimental. These two documents appear to be in conflict concerning this issue.

5.6 ISSUE 6: LACK OF DATA VALIDATION AND VERIFICATION

The validation and verification of the data used in dose reconstruction has not been adequately completed. There are indications that additional bioassay data exist that are not reflected in the database obtained by ORAU for the calculation of MDAs. For example, we became aware that ORNL has not fully consolidated all the occupational exposure records, indicating that some records may not be complete. Also, the completeness and accuracy of the external dosimetry data may require further verification to ensure field-recorded dose results were integrated into occupational exposure records (OERs). This adds to uncertainty of these data. Finally, the environmental air sampling data ratios used in the development of co-worker dose from Ru-106, Ce-144, and Cs-137 should be further justified.

5.6.1 Data Completeness

OTIB-0034 (Kennedy 2005) indicates that the co-worker doses were derived from a dosimetry database used by ORISE in epidemiologic studies:

> *Bioassay results for ORNL were obtained from the Oak Ridge Institute for Science and Education (ORISE) Center for Epidemiologic Research (CER) Dosimetry Database, which contains records from ORNL site for the period 1951–1988. ORISE obtained the database for the purpose of conducting an epidemiology study of site workers. The database results are in units of disintegrations per minute (dpm)/24 hours* (Kennedy 2005, pg. 6).

The MDA values were derived from what appears to be a second database. The Internal Dose TBD indicates this database contains results from 1947 to 1988 (Bollenbacher et al. 2006, pg. 34).

> *The electronic data that were provided by ORNL for use in estimating isotopic MDAs came from a project performed in the early to mid-1990s to convert hardcopy data over to dBase IV database. Funding ran out on the conversion project in the mid-1990s and the entire set of data was never completely converted, but a significant number of results were made available for our use* (Bollenbacher et al. 2006, pg. 9).

SC&A is concerned that the database used for the MDA calculations may be incomplete, and additional pertinent bioassay data to dose reconstruction for monitored and unmonitored workers may exist. For example, Table 5-9 provides an MDA for tritium in urine starting in 1961. An

early procedure for body fluid analysis, dated January 1957, states the following (Brown et al. 1957):

> *Body fluid analysis are made routinely by the Bio-Assays unit for H-3, Po, Pu, Ra, Sr, U, Gross Alpha (Th, Pu, Am, Cm) and Gross Beta (including K-40).*

Potential for tritium exposure extends back to at least the 1950s. For example, the Homogeneous Reactor Experiment – II used a fuel solution of enriched uranium sulfate (U_2S_{O4}) dissolved in heavy water (Huang et al. 1984). This reactor was in operation from 1957–1961. Reactors using heavy water at the Savannah River Site (SRS) contributed significantly to tritium dose. Although the database was evaluated for duplicate records and usability, the database was not evaluated for completeness.

To further complicate matters, it is unclear whether the hardcopy records provided are complete. Occupation Exposure Records (OERs) were maintained in several different locations, making it difficult to readily retrieve an individual's complete exposure record. In the 1990s, the Laboratory began a project to consolidate OERs into a single location. This process was not completed, due to lack of funding. The TBD states the following (Bollenbacher et al. 2006, pg. 14):

> *Many hardcopy records have been consolidated into individual personal records folders. However, this compilation is incomplete, with records for only employees with last names beginning with A through G.*

One source of information absent from both the medical and radiological files at ORNL are the records of voluntary human radiation experimentation by ORNL workers. Two such studies are described below:

> *During 1944 and 1945 the Clinton Laboratories, in cooperation with the Medical Division, placed P-32 beta-emitting plaques on the arms of 18 employee volunteers to study the skin erythema dose (Morgan and Peterson, 1999).*

And,

> *In 1962, S.R. Bernard of the ORNL HP Division administered I-131 to himself and other volunteers in his research group. The level of activity neared the maximum permissible concentration for members of the public (Morgan and Peterson, 1999).*

These situations can result in significant dose consequences to particular organs and should be included in the dose reconstruction of claimants involved. According to ORNL staff, the personnel involved in these activities are listed in a database. NIOSH ought to evaluate whether any claimants are included in this database and retrieve reports or other documentation relevant to these experiments.

5.6.2 Data Accuracy

During site expert interviews, former workers raised concerns to SC&A regarding the completeness and accuracy of historic ORNL radiation exposure records. Particular concerns were related to unauthorized practices, such as removal of routine film badges during high dose rate jobs, wearing film badges under protective clothing versus over clothing during routine work, and removing film badges. These issues were allegedly a systemic issue over the site as being referred to by Karl Morgan in his book (Morgan and Peterson 1999):

> *Careless former college professors presented disdain for health physics restrictions. Ironically, the trust and high respect we received from the blue collar workers sometimes failed to transfer to certain scientists.*

Morgan also discussed the combination of the film and security badges (Morgan and Peterson 1999):

> *Although we issued a film badge to everyone exposed to ionizing radiation, some employees left their badges at home or on the desk in their office….we arranged to combine the film base with the security badge. Now the film badges contained space for a picture of the employee and his or her security number. No one dared be seen in the restricted area without the proper badge.*

One particular situation relayed to SC&A occurred in the first half of 1981. Approximately 70 pipefitters and 20 welders were brought from all over the site to assist with a Cell Tear Out Site-wide in Building 3517. The stay time for this particular job was very short, and air-supplied suits had to be worn because of the radiation and contamination levels. The crafts personnel indicate that the dosimeter was removed and they were sent in with PICs. Health Physics personnel indicated that the routine quarterly dosimeter was removed, and a special job-specific dosimeter was used. HP indicates the special dosimeter for that job clipped to their inner set of coveralls. Their routine quarterly dosimeters were removed while they were wearing the job-specific dosimeters. About half of the workers were issued PICs. Some workers were also issued finger rings (extremity dosimeters). The special dosimeter, PIC, and finger ring readings were recorded on Radiation Survey Complex Reports (see Attachment 2). A review of the Radiation Survey Complex Report for Building 3517 for March 1981 indicated that 28 maintenance employees had pocket meter readings in excess of 100 mR/week. Forty-four (44) maintenance employees had "films processed out of routine." The non-routine badges listed for the 44 maintenance employees appear to have been worn for a period of 1–6 days. There was no mention of bioassay for these personnel on the Building 3517 form. The results listed appear to indicate a predominance of beta exposure (RSCR 1981). The practice of using special dosimetry or even pocket dosimeters, in lieu of routine film badges, should be evaluated to ensure these doses are reflected in the Occupational Exposure Records and associated databases. The increase in frequency of exchange and relative shielding of the beta radiation could also influence any missed dose in these situations.

SC&A is also concerned about the approach taken for the determination of co-worker dose from additional radionuclides (i.e., Ru-106, Cs-137, and Ce-144). OTIB-0034 (Kennedy 2005, pg. 11) states the following:

> *To account for additional intakes, an evaluation of air monitoring data from the ORNL perimeter reporting stations for the period 1975 through 1984 was conducted. The approach was to develop the ratios of the isotopic concentration ratios of other radionuclides to the concentration ratio of Sr-90 report in the air monitoring data.*

During the Tiger Team assessment of ORNL, 7 of the 18 ambient air sampling stations were examined. Three of these samplers were not at the recommended height of 2.0 meters. Four of the air sampling stations were too close to buildings and trees. Although they only looked at 7 of the stations, there was concern that other stations may have deficiencies. The Tiger Team also found that 6 of the 11 radionuclide stack monitoring systems examined had some air monitoring deficiencies (DOE 1990):

> *… poor sample extraction sites, unsuitable sample transport line configuration, absence of air flow measurements, an inappropriately designed sampling probe, and a non-operational strip chart.*

There are several issues with the use of ratios to determine occupational dose from Ru-106, Cs-137, and Ce-144. First, an environmental air sample represents a conglomeration of radionuclides from multiple release points, rather than being facility specific. Second, as indicated above, there are deficiencies with the stack monitoring and ambient air sampling program that have not been taken into account. Finally, it is not clear how the period of 1975 through 1984 is representative of years outside this range, given that operations at ORNL are transitional.

In summary, SC&A is concerned about the lack of verification and validation of the databases used to determine MDAs and co-workers' dose. There appears to be data absent from these sources that is pertinent to dose reconstruction. There is also concern over the completeness of the hardcopy records supplied by ORNL to NIOSH. The reliance on an incomplete database and dispersed exposure records may raise questions regarding the completeness and accuracy of internal and external dose estimates. As a compensatory process, SC&A is not aware of any effort to collect bioassay data known to be absent from this database. SC&A is also not aware of any effort to independently validate its reliability by comparing the electronic bioassay results with available dosimetry printouts and forms, logbooks, air sampling data, or other sources. This type of validation and verification is recommended.

5.7 ISSUE 7: THE TBD FAILS TO ADEQUATELY DEFINE AND ASSESS OCCUPATIONAL MEDICAL EXPOSURE

The current medical exposure and dose guidelines, as presented in (Kathren 2003), goes a long way in assuring that all occupational medical exposures are reasonably included in determining

the overall dose estimations for claimants. Unfortunately, the interpretation, to date, by the contractor (ORAU) has not been applied conservatively to be claimant favorable. The Occupational Medical Dose TBD (Fleming 2006a) assumes an interpretation, which has been also considered and applied at other sites, such as the Mound Plant and Los Alamos National Laboratory (LANL), Paducah, and Pinellas. To this extent, the assumption that medical procedures are limited to only one pre-employment chest x-ray and chest x-rays that are part of routine physical exams, may substantially underestimate worker medical exposure, when evaluating occupational medical exposure.

In more recent documentation (OTIB-0006, Revision 3, Kathren and Shockley 2005), it is concluded that other examinations should be included, such as special screening exams (e.g., respiratory protection, beryllium workers, asbestos workers, etc.) and termination exams. The Occupational Medical Dose TBD (Fleming 2006a) does not recognize this change from the previous Revision 2 of the OTIB-0006 (Kathren 2003), and also assumes that special chest radiography for respirator certification, beryllium, and asbestos workers, and food handlers are accomplished as part of the routine physicals. This is not documented in the medical TBD. Another factor not discussed in the TBD is the potential and impact of x-ray procedures utilized by medical authorities to do special screenings that are performed outside the frequency suggested in the TBD or at alternate locations. The Oak Ridge Reservation had numerous sites and contracted with numerous radiology services and hospitals that provided these services upon request.

The TBD (Fleming 2006a) makes the conclusion that chest examinations are often quite limited after 1970, after which chest x-rays were voluntary. Oak Ridge also did upper GI fluoroscopy and lumbar spines up through 1953; however, no specific recommendation is given to dose assessors. It is suggested the policy after 1990 called for a chest x-ray every 3 years before age 40, and every 2 years after age 40, but nothing is documented. To the contrary, there is ample evidence that chest x-rays were often provided on a voluntary basis to nearly all workers, usually on an annual basis. The majority of workers had chest x-rays annually as a routine at DOE sites until the mid-1980s, when Federal guidelines warning against routine screening were first being enforced.

After discussion with NIOSH personnel, it was their decision to limit occupational medical exposure to those chest exams described above, except for some lumbar spine exams in 1950 to 1953, and to include all other exposure as part of worker non-occupational medical dose. SC&A believes such an interpretation is not claimant favorable to those most at risk. Our concern is that specified “high-risk” workers, those most likely exposed to radiation and beryllium, would be at risk of having an incomplete dose assessment if not all radiation associated to medical screening for job-related activities were included. Since all radiation provides some risk, and arguably, is cumulative, workers warrant consideration of all forms of work-related x-ray exposure to be claimant favorable. SC&A believes NIOSH should review its interpretation of included medical exposure, and should reasonably adopt a broader interpretation of occupational medical dose, as provided in the most recent version of OTIB-0006 (Kathren and Shockley 2005).

5.8 ISSUE 8: TECHNIQUES AND PROTOCOLS INCREASE UNCERTAINTY OF DOSE CONVERSION FACTORS LISTED IN THE TBD

Section 3.5 of the Occupational Medical Dose TBD (Fleming 2006a) fails to describe adequately all the information upon which to establish beam quality for x-ray units in use from 1943. In 1947, the site documented installation of a single phase Picker R-2 unit. There is only limited documentation to show that the Picker unit, in use from 1947 through 1963, had added filtration—approximately 1.0 mm of aluminum, as first measured by Gupton, in the 1958 surveys (Gupton 1958a and 1958b). In the absence of definitive tube output measurements, the TBD directs the use of default values and dose conversion factors (DCFs) derived from ICRP Report No. 34 (ICRP 1982). These values are then applied to determine organ doses using Tables A.2 through A.8 of ICRP Report No. 34 (ICRP 1982). An issue of concern is that the DCFs are derived using a default half-value layer of 2.5 mm Al for Type 1 units in use from 1946–1980 (whereas the Picker unit had substantially less filtration).

The TBD (Fleming 2006a) provides little documentation to support the assumed techniques and protocols applied to calculate the dose, which is mainly derived from NCRP Report 102. The TBD states that a PA chest x-ray was typically the only view taken. It is an undocumented assumption in the TBD that exams required only a PA view. SC&A has inquired whether definitive protocol existed to validate that chest exams possibly included PA views and LAT views on a limited basis. NIOSH has acknowledged in other TBD reviews that the lack of verifiable protocols is a generic problem at many sites, has planned to search all available records, and will include pertinent records and references in any future revision of this section of the TBD.

The TBD is also deficient in that little documentation exists to validate x-ray protocols, equipment maintenance, and upkeep records.

5.9 ISSUE 9: FREQUENCY AND TYPE OF X-RAY EXPOSURE IS UNCERTAIN.

The Occupational Medical Dose TBD (Fleming 2006a) relies on a limited review of archived medical records to establish frequency assumptions. The assumption of one chest radiograph (PA) after 1970 on a voluntary basis is not reasonably conservative, in that workers could essentially request an x-ray or be subject to special screening exams. The frequency of screenings, and number and type of workers receiving extra annual x-rays is not evaluated.

The TBD (Section 3) does not provide any documentation or references to support the assumption that only a limited group of workers received annual x-ray exams after 1970. To the contrary, up until about 1985, most DOE sites performed chest x-rays almost on a voluntary basis. DOE medical program reviews documented during the early 1990s showed many sites still used chest radiography as a general screening exam. Most workers accepted chest x-rays, even though the job did not require it. Also, the assumption that workers in special exposure categories, such as beryllium workers, were given chest x-rays only as part of their routine physical is not well-documented and not consistent with special screening guidelines. The TBD applies no conservative assumption to cover such exams.

The TBD (Section 3.2) states that photofluorography (PFG) units, although generally available up to the late 1950s at most DOE sites, were not documented as being used at the ORNL, but were in use at the Oak Ridge Hospital from 1943–1947. The undocumented absence of PFG units at ORNL clearly has significant dose implications to workers who may have been given much higher doses from PFG units. The PFG unit provides a dose to the worker greater by a factor of 5–6, more than that delivered by conventional radiography. The TBD does not provide documentation for the types of equipment in use at ORNL prior to 1947. SC&A believes it is not claimant favorable to instruct dose assessors to assume only PFG unit use from 1943–1947. To be fully claimant favorable, it would be appropriate to instruct dose assessors to use an annual dose of 3.0 rem per year for chest radiographs, in accordance with guidelines set forth (Kathren and Shockley 2005), until the review of medical records evidenced no further use of a PFG unit at any Oak Ridge site or contractor location (two Oak Ridge area hospitals and local radiology clinics were also used to do x-ray examinations).

5.10 ISSUE 10: INADEQUATE CONSIDERATION OF ENVIRONMENTAL DOSE FROM RADIONUCLIDES OTHER THAN I-131 AND TRITIUM.

The Occupational Environmental Dose TBD (Fleming 2006a) focuses on onsite airborne I-131 concentrations, onsite airborne concentrations of MFPs, onsite airborne concentrations of tritium, and onsite exposure rate data. Reactors' releases and waste farms data are not adequately considered.

In Section 4.1, the TBD indicates the existence of site-wide monitoring data for external exposures dating back to early in the Laboratory's history, but little information was available regarding airborne concentrations of the two principal nuclides considered for inhalation exposure, i.e., I-131and tritium. Regardless of data limitations for these two isotopes, we believe that site contamination is not limited to these two elements only. ORAUT-TKBS-0012-2 clearly and rightfully stated that the ORNL site has been used to test new ideas for DOE and other agencies since inception in 1943. Many of the earliest buildings at the site have transitioned through various mission objectives. Thus, all types of radioactive contaminants were expected to be found at this site, not only I-131 and tritium. In Section 2.1 of the TBD, a partial list of the reactors that were designed and, in most cases, tested at ORNL, and then either scrapped or further developed elsewhere, included the LITR, CEF (at the Y-12 National Nuclear Security Complex), BSR)/PCA, ORR, TSR, HPRR, HRE, ANP Program, the HFIR, and the MSRE. Section 2.1 additionally emphasized that waste radioactive material was released from early site operations as gaseous, liquid, and solid effluents, with little or no pretreatment. Later, methods were developed to capture many of the contaminants at their source and to reduce overall plant emissions. In some cases, this increased direct exposures to individuals in the area and created locations in which incidents and spills occurred (Fleming 2006).

Radiological discharges from each stack were unique because of the variety of research activities on site. Emissions from ORNL typically consist of solid particle, absorbable gases, tritium, and nonabsorbable gases (DOE 1990). In section 2.2.7, the Site Description TBD clearly identified an array of isotopes that were released from only one building; the Graphite Reactor. The quote of that section is as follows (Fleming 2006b, pg. 10):

> *Radionuclides produced in the reactor included ^{35}S, ^{32}P, ^{31}Si, ^{42}K, $^{41-45}Ca$, ^{46}Sc, ^{51}Ti, ^{59}Fe, ^{55}Fe, ^{60}Co, ^{65}Ni, ^{64}Cu, ^{75}Se, ^{110}Ag, ^{114}In, ^{115}Cd, ^{124}Sb, ^{152}Eu, ^{154}Eu, ^{155}Eu, ^{182}Ta, ^{185}W, ^{185}Os, ^{191}Os, ^{193}Os, ^{204}Tl, ^{206}Tl, ^{210}Bi, ^{24}Na, ^{76}As, ^{82}Br, ^{86}Rb, ^{99}Mo, ^{198}Au, ^{131}I, $^{141-143}Ce$, ^{14}C, and ^{192}Ir. Activation of the cooling air resulted in the chronic release of ^{41}Ar from the Building 3018 stack whenever the reactor was operating. In 1948, ^{41}Ar releases totaled 540 Ci d^{-1} at a reactor power of 4,000 kW(t) and an exit airflow rate of 51,000 cfm. Fuel slug ruptures in 1947 resulted in emissions of ^{131}I, ^{133}I, ^{129}I, ^{137}Cs, ^{90}Sr, ^{85}Kr, ^{133}Xe, ^{239}Pu, ^{103}Ru, ^{106}Ru, ^{144}Ce, ^{140}La, ^{140}Ba, ^{95}Zr, ^{89}Sr, ^{235}U, ^{238}U, and ^{95}Nb.*

In addition, Table 2-2 identified many radioactive elements of concern at the North Tank Farm (Building 3023 or 206). These radioisotopes of concern include U-233, U-235, Np-237, Am-241, Pu-238, Pu-239, Sr-90, Cs-137, Co-60, and tritium. Radioisotopes of concern from the South Tank Farm (Building 3507or 206) include U-233, U-235, Am-241, Pu-238, Pu-239, Sr-90, Co-60, and tritium (Fleming 2006b).

The X-10 facility handled irradiated thorium, radioactive lanthanum, and plutonium. Airborne effluent emissions from that plant included U-233. This isotope has a much higher specific activity, and somewhat higher effective dose coefficients, than the other uranium isotopes. Thus, if this nuclide was included in the total uranium (expressed in $\mu g/m^3$) measured at the Y-12 facility, it would have a significantly greater radiological impact. Furthermore, when U-233 is produced by irradiating Th-232 in a reactor, U-232 is an inevitable byproduct. Although its mass concentration is in the range of 5–50 ppm in the uranium metal, it has an extremely high specific activity, due to its short (68.9-y) half-life, and has effective dose coefficients that are several times higher than those of U-234.

The Occupational Environmental Dose TBD (Burns 2004b) also has not considered environmental exposures to ORNL personnel assigned to areas at the Y-12 Plant. Environmental air monitoring at the Y-12 Plant focused on evaluating releases of U-234, U-235, and U-238. It appears reasonable that if the Y-12 workers were exposed to airborne uranium, the ORNL workers located at Y-12 would also be exposed to the same uranium.

Because of these facts, additional elaboration in the document is needed to explain the methodologies used to take into account the environmental contamination consequences and exposure of involved and uninvolved workers to this wide array of radioisotopes.

5.11 SECONDARY ISSUES

5.11.1 Secondary Issue 1: Potential for High-Fired Oxides

The ORNL Site Description TBD (Fleming 2006b, pg. 25) states the following:

> *In addition, Building 4508 housed the Fuel Cycle Alpha Facility (FCAF), which fabricated plutonium oxide and plutonium-uranium oxide fuel pellets, and was*

used for coating sol gel-derived microspheres with pyrolytic carbon. In addition, special target materials for the HFIR were developed and fabricated.

These processes occurred in Building 3019 and 4508. It is noted that gloveboxes were equipped to synthesize, press, and sinter pellets of Pu and U nitrides in Building 4508. It would appear that there may have been the potential for creation and possible exposure to high-fired oxides in some of these processes. The TBD makes no reference to the potential of producing such forms, or how they would be handled if such insoluble forms were produced in these processes. The possibility for or against creation of such forms should be addressed, since Super S forms have been found and noted at most other DOE facilities processing plutonium.

5.11.2 Secondary Issue 2: Ingestion Pathway is Not Addressed

The Occupational Internal Dose TBD (Bollenbacher et al. 2006) does not address or consider potential exposure from the ingestion pathway, especially a potential issue in the early years. Many of the radionuclides handled at ORNL were highly soluble. Review of the *ORNL Internal Dosimetry Program Technical Basis Document*, Revision 7, December 21, 2005 (McLaughlin 2005), references ingestion 74 times. McLaughlin 2005 addresses ingestion intake retention fractions (IRF), and page 57 of that document presents a section on "Internal Dosimetry Software Used at ORNL," which discusses acute ingestion and chronic ingestion pathways. Page 69 of the TBD addresses DCFs for ingestion intakes. It appears that the Internal Dosimetry Program at ORNL recognized and calculated internal doses from ingestion intakes. The Occupational Internal Dose TBD (Bollenbacher et al. 2006), however, appears silent on this issue. SC&A suggests that this pathway needs to be addressed in the TBD.

5.11.3 Secondary Issue 3: Lack of Explanation for Determining MDAs

Section 5.1.5 (Bollenbacher et al. 2006, pg. 12) states that ORNL has entered much historical in-vitro monitoring data into a database. In Section 5.1.1, it states that the values in Table 5-1 do not reflect the total number of in-vitro bioassays performed by ORNL in this period, because not all hardcopy records are in the database. These statements are difficult to interpret, and the numbers in the tables seem to match fairly well. However, the numbers of samples analyzed and used to determine historical MDAs appear to be extremely small in many cases with a sample size less than 10, and there are a large number of single samples used for determining the MDAs (Table 5-1, pg. 10, and Table 5A-1, pg. 36). Are these really most of the analyses that were done on workers for many of these radionuclides? NIOSH should further evaluate a method for determination of MDA values with an adequate number of data points including those for other radionuclides.

There needs to be much more explanation of what was going on with the large variations in MDA values (dpm/24-hour sample) for some of the radionuclides listed in the TBD (Table 5-9, pg. 16, and Table 5A-2, pg. 39). Specific examples include uranium and Ru-106. The uranium MDA (Table 5-9, pg. 16) goes from 1.4 in years 1948 through 1950, then up to 6.3 in years 1951 through 1963, and then back down to 1.1 and 0.09 and 0.06. The MDA for Ru-106 goes from 0.30 in years 1951 through 1959, and then jumps up to 53. Was the MDA really lower in the

early years, and, if so, why? It is obvious that MDA values would improve and go down as better analytical techniques and methods are discovered. The uranium analysis data in the years 1951 through 1963, using the jump up in MDA values, raises concern for missed dose for those claimants. If you really had MDA values for Ru-106 of 0.036 in 1951, why would you change to an analytical procedure that gives an MDA of 78.9 in 1964 (Table 5A-1, pg. 39). SC&A feels that further explanation is needed for some of the obvious discrepancies in MDA values over time.

5.11.4 Secondary Issue 4: Other Potential Medical Exposures Have Not Been Identified

The Occupational Medical Dose TBD (Fleming 2006a) does not address the potential use of radiation exposure from exposure sources other than x-ray units, in the support of medical diagnosis. This may involve the use of isotopes, sealed sources, etc. The TBD is also deficient in that it does little to catalog the number, types of x-ray equipment, frequency of use, etc., discussed above in Issues 2 and 3.

The below average performance at ORNL to conduct routine and preventative maintenance during the 1947–1990 timeframe suggests that routine maintenance of x-ray units was not likely, unless performed by an unknown outside contractor. Unfortunately, no records exist to evidence maintenance, calibrations, etc. The lack of defined protocols and basis for approval of radiography procedures suggests that the use of radiography was not closely controlled. The Occupational Medical Dose TBD does not discuss the use of portable radiography to perform screenings, and the potential for exposure of medical personnel or other workers without dosimetry devices being utilized. This is potentially an issue for the PFG unit, which was often van-mounted at other sites.

The conclusion is that the TBD does little to reasonably document the variety of medical occupational exposures, and the lack of documentation on the type of equipment and the maintenance records does little to assure that a conservative and claimant-favorable estimation of dose is possible. This circumstance would suggest the need to reconsider a worst-case approach to establishing dose. NIOSH should revisit and update, as needed, Sections 3.4 and 3.5 of the TBD.

5.11.5 Secondary Issue 5: Additional Factors Contribute to Uncertainties

The Occupational Medical Dose TBD (Fleming 2006a) does not consider dose impacts due to less-than-optimal use of technology, such as using screens, grids, or bucky systems. The TBD does not consider these elements as potential contributions to uncertainty.

The TBD does consider the potential contribution to dose that may have resulted in less-than-optimal use of collimation, at least prior to 1970, as stated in Section 3.5 of the TBD. Unresolved is the concern that the DCFs are derived from ICRP Publication 34 (ICRP 1982), and therefore, are not comparable in terms of beam quality, which varies from unit to unit. These factors can contribute greatly to the dose to the chest and other organs for the units in operation prior to 1990, as little or no documentation exists. NIOSH has indicated in other TBDs that it

will continue to search for other available records to better define equipment use and beam quality, and include it in an updated version of the TBD, as appropriate.

Uncertainty as defined is the TBD as being due to measurement error, and variation in kilovoltage, tube current, timers, and the source-to-skin distance. This approach is quite similar to the uncertainty analyses documented in other DOE site profiles. The conclusion in this TBD (and others) is that an uncertainty factor of +30% should be used by dose reconstructors. SC&A believes the uncertainty correction factor of 2.0 (being applied at other sites) is more appropriate in order to ensure claimant favorability.

SC&A agrees that the TBD conservatively estimates these essential aspects of an uncertainty review. Unresolved is the contribution to uncertainty in dose, due to other errors introduced by lack of quality controls in processing equipment and lack of adherence to established standard operating procedures. A reasonable estimate of these contributions to uncertainty would be an evaluation of retake rates, per examination type. NIOSH should revisit the potential for significant retake rates and evaluate its potential effect on dose as part of future revisions of this TBD, especially as it relates to prior to 1990, when photo timing of exposures was adopted.

The TBD does not show that ORNL applied dose minimization principles to reduce medical exposures. The document also does not assess or consider the likely exposure to workers who are referred to offsite medical facilities for follow-up. The TBD states that review of selected medical records and files did not reasonably show or match expected x-ray exam frequency and type of exam, as shown in Tables 3.2 and 3.3. Little evidence exists to document the number of x-ray exams provided to the average worker or for special exposure needs.

5.11.6 Secondary Issue 6: Average Annual Environmental Exposures

The Occupational Environmental Dose TBD (Burns 2004b) states that a number of conservative approaches and assumptions had to be employed to develop the requisite concentration and intake data. These results should be considered more bounding than representative. SC&A believes that this could be a reasonable approach only if the approach is proven claimant favorable. Also, it is not clear how the annual "average" airborne concentrations and annual "average" exposure rates are bounding. Environmental doses to local workers following accidents and spills can be significant. Limiting the doses to airborne releases, as alluded to in Section 4.2 of the TBD, is certainly undermining the dose contributions from environmental sources. It is unclear how the average values of releases took into account the releases and deposition of large amounts of radioactive contaminants at the site. Several examples in the TBD clearly identified these releases and potential precipitation of radioactive particles (Burns 2004b, pp. 6 and 7). Several quotes are given below.

> *The exhaust air from the Graphite Reactor was discharged unfiltered until 1948 when a significant particle contamination problem was found on the Laboratory grounds. The Graphite Reactor was found to be one of the principal contributors to this particulate contamination, so a filter house was added between the exhaust plenum and the stack. The filtration system, which became operational in*

> *November 1948, consisted of parallel banks of roughing plus high-efficiency filters. Particulate releases from the 105 stack were largely mitigated once the filtration system was added. The 105 stack also ventilated gaseous effluents from the Low-Intensity Test Reactor (LITR) from 1949 until 1968* (Burns 2004b, pg. 6).
>
> *…high-activity offgas streams were ventilated via the 205 stack prior to completion of the ORNL central offgas handling system about 1950* (Burns 2004b, pg. 7).

Furthermore,

> *Prior to 1950, airborne radioactive effluents from ORNL were discharged to stacks and vents serving individual facilities. However, the temporary nature of the Laboratory's original mission resulted in it quickly outgrowing its waste handling measures once its status was changed to one of indefinite duration* (Burns 2004b, pg. 7).

In the Site Description TBD, similar descriptions were made to justify our concerns regarding the claimant-favorability approach in dose reconstruction (Fleming 2006, pg. 24):

> *Other than operational problems (failed equipment, breached control systems, plugged feed lines) that occurred at times during RaLa operations, the worst incident occurred at about 5:00 p.m. on April 29, 1954. The incident was described as "the most serious accidental release of activity ever experienced in the history of the process" (Rupp and Witkowski 1955). The Building 706-D …….. When the fourth batch addition of acid was poured into the dissolver to initiate additional dissolution, a violent reaction occurred, forcing dissolver solution up the slug-loading chute and solution addition lines. Air monitors in the building immediately sounded an alarm, indicating elevated airborne radioactive material. The investigation that followed indicated that individuals in the building donned gas masks and evacuated the building soon. The release lasted from between 10 min to 2 hr before the scrubbers could recover and begin filtering radioiodine from the building. A letter written by the Laboratory Shift Superintendent to the ORNL Director indicated "all people involved in the incident and later in the high level decontamination work are being given the standard HP check including urine checks, etc." (Stanley 1954). Radiation levels reached **100 R hr-1** on the third floor, but were reduced to 100 mR hr-1 by 7:00 a.m. the next day; air sample results did not exceed the tolerance level of 3.0E-08 µCi ml-1. A preliminary check of film badge results was indicated as having been conducted, but the reference did not provide confirmation.*

From the brief description above, several issues might require additional assessments. One of them is the uncertainty of the release duration. A release of 10 minutes to 2 hours is a wide range to accurately define dose. Also, the appropriateness of the use of site-wide average exposure rates was questioned by the authors of the TBD, particularly for cases in which a

composite exposure profile for an unmonitored individual is inconsistent with a known or asserted exposure history. The third concern is the acute exposure to 100,000 mrem/hour for 2 continuous hours.

Therefore, SC&A believes that the Occupational Environmental Dose TBD (Burns 2004b) should be supplemented with a detailed discussion of associated uncertainty analysis on airborne concentration data and exposure data. Also, we wonder if uncertainties have been quantified, and if they have been utilized in the environmental dose reconstruction.

5.11.7 Secondary Issue 7: Inadvertent Ingestion and Inhalation of Resuspended Particles Not Considered

Despite the fact that the Occupational Environmental Dose TBD (Burns 2004b) is continuously assuming that the air monitors at the site intercept and take into account resuspended particles, SC&A is concerned that the assumption may not be correct. Depending on the height of the air monitors, these particles can play an important role in dose reconstruction of unmonitored workers. For example, the extent of soil contamination at ORNL is documented in surveys that can be obtained from http://risk.lsd.ornl.gov/maps/x-10/x10_relsites.shtml.

Another concern is the admission of DOE itself that contamination due to radioactive releases is large, particularly for certain processes in the early days of ORNL operation. Of particular interest is the following statement:

> *…Specific attention is given to the production of RaLa and the fission products I-131 and Cs-137. RaLa production for nuclear weapons development reached its height during the late 1940s and early 1950s, which resulted in rarely monitored or restricted releases of I-131 and other short-lived fission products. ORNL also manufactured I-131 and Cs-137 for therapeutic use in the private sector and its own research needs. The production and onsite use of these nuclides resulted in both deliberate and unplanned environmental releases. Moreover, these nuclides were prevalent in the large quantities of liquid waste and airborne contaminants that have been discharged and monitored at the ORR since the 1940s.*
> http://www.eh.doe.gov/ohre/new/findingaids/epidemiologic/oakridge3/intro.html

SC&A is concerned that the resuspension factors of these contaminated soils, which should be used to derive doses to workers from inhalation or ingestion, were not fully addressed. As we indicated for SRS and Rocky Flats Plant (RFP) site reviews, there are a couple of methods to estimate inhalation exposure from resuspended radionuclides. These methods include the dust-loading approach and the resuspension-factor approach. In addition, SC&A refers to Section 1.1.3 of this report regarding our concerns of the appropriateness of the air monitoring network and locations, and hence, the reliance on its data to intercept particles' resuspension.

6.0 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.

6.1 SATISFYING THE FIVE OBJECTIVES

The SC&A review procedures, as approved by the Advisory Board, require that each site profile be evaluated against five measures of adequacy; (1) completeness of data sources, (2) technical accuracy, (3) adequacy of data, (4) site profile consistency, and (5) regulatory compliance. The SC&A review found that the NIOSH site profile for ORNL presents an adequate accounting of the primary internal and external issues related to predominant radionuclides, such as uranium, plutonium, and some fission products. The ORNL Site Profile falls short in fully characterizing a number of key underlying issues that are fundamental to guiding dose reconstruction. In some cases, these issues may impact other site profiles. Many of the issues involve lack of sufficient conservatism in key assumptions or estimation approaches, or incomplete site data or analyses of these data. Section 6.0 summarizes the key issues. A detailed evaluation of these issues is provided elsewhere in the report.

6.1.1 Objective 1: Completeness of Data Sources

The breadth of data sources used as a basis for the ORNL Site Profile is evident in the 472 reports available for ORNL in the Site Profile Research Database. Two hundred twenty-six (226) reports were cited in the site profile references, while others served to provide confirmatory information, or were only recently retrieved. The NIOSH/ORAU team consulted health physics personnel with long histories at ORNL who have extensive knowledge of key dosimetry historical processes and personnel monitoring data. There was a meeting held with the ORNL Labor and Trades Council on November 8, 2004, in order to identify worker concerns and discuss the TBDs. This interaction has helped to provide valuable insight into site operations and processes. In addition, the issuance of supporting TIBs reflect the ongoing effort by NIOSH to continually improve guidance provided to dose reconstructors.

However, the site profile falls short in its critical evaluation of pertinent records and purposeful use of site expert interviews to ascertain potential monitoring or records gaps throughout ORNL's history, with the objective of determining the extent and significance of unmonitored worker dose. This issue is particularly acute among workers who were transient onsite, and between the Y-12 Plant and Bethel Valley locations. Until the 1990s, there was a reliance on the

field to determine when and what bioassay was required. Audits in later years indicated the inconsistencies that exist in the Radiological Control program, especially between the Bethel/Melton Valley location and the Y-12 Plant location.

The validation and verification of the data used in dose reconstruction has not been adequately completed. There are indications that additional bioassay data exist, which are not reflected in the database obtained by ORAU for the calculation of MDAs. For example, ORNL has not fully consolidated all the occupational exposure records, indicating that some records may not be complete. Absence of bioassay data in the database is also evidenced by the existence of source term and bioassay techniques for some radionuclides prior to the initial MDA calculated in the TBD. Based on Comprehensive Epidemiology Data Resource (CEDR) data retrieved by ORNL, the urinalysis program was diverse and bioassay data was available for 63 radionuclides. Many of these radionuclides had less than 10 samples from the period of 1947–1988. Other radionuclides handled at ORNL were not available in the database, many of which were listed in the Site Description TBD. Further evaluation of secondary radionuclides is necessary to ascertain the potential missed dose to workers. Finally, the environmental air sampling data ratios used in the development of co-worker dose from Ru-106, Ce-144, and Cs-137 should be further justified.

In terms of environmental dose, those workers permanently assigned to ORNL operations at the Y-12 Plant were not considered separately from those at Bethel/Melton Valley. The environmental dose measurements concentrated on I-131 and tritium exposure, while the predominant source of environmental release at the Y-12 Plant was uranium. The ORNL TBD authors are encouraged to review the Y-12 TBD to determine the unique hazards associated with this location.

6.1.2 Objective 2: Technical Accuracy

The Occupational Medical Dose TBD (Fleming 2004) provides little documentation to support the assumption that techniques and protocols applied to calculate the dose (mainly derived from Cardarelli et al. 2002) is accurate. NIOSH believes that when no information is readily available about the energy spectrum, it is reasonable to use the assumptions for DCFs presented in the Implementation Guide.

The Occupational Environmental Dose TBD (Burns 2004b) appears to rely on emission and measurement data; however, it does not indicate the model used for calculations. The TBD generally discusses particle size; however, the actual particle size assumptions for assignment of internal dose have not been provided. No consideration has been given to the deficiencies in the stack and ambient air sampling systems; however, there is a heavy reliance on these systems to determine unmonitored worker dose. Exposures considered are limited to I-131, H-3 (starting 1967), Kr-85, Xe-133, and MFPs (optional), while diverse radionuclides were handled and potentially released at the site. There has been no consideration of potential doses from the release of large uranium particles. Overall, SC&A believes that further investigation into environmental source terms and pathways is needed.

The Occupational External TBD (Burns and Mohrbacher 2004) may result in an underestimate of neutron dose. Neutron dose is determined from NTA film results, and is modified with a correction factor. Some facility-specific neutron energy bands are provided; however, in some facilities, the entire spectrum is essentially below the practical 1-MeV detection limits of NTA film used in the workers' badges. From the information in the current Occupational External Dose TBD (Burns and Mohrbacher 2004), it is not obvious that the dose reconstructor has sufficient detailed correction factor/instructions available to correct for the unmonitored neutron doses resulting from neutrons with less than 1 MeV of energy at the numerous facilities at ORNL that produced neutron exposures through the years.

Unlike other TBDs, there is a lack of defined procedures on how to assign missed dose to unmonitored workers. There needs to be clear direction on how to assign missed dose to ensure consistency among dose reconstructions and prevent confusion.

Information available for the dose reconstruction in the early years is limited, inadequate, and in some cases, not available. External monitoring for 1943–1944 was limited to the use of PICs with some experimental badges worn. There is a lack of clear discussion on how these monitored and unmonitored doses are derived during this time period. Furthermore, the Occupational External Dose TBD (Burns and Mohrbacher 2004) questions the validity of these data. The monitoring practices for the years prior to 1951 require further investigation to determine if all exposed workers were monitored during this time period. In terms of internal exposure, there was an absence of routine internal monitoring until 1949. Early bioassay data were limited to plutonium and strontium, although other radionuclides were being handled even prior to 1949.

The Occupational Internal Dose TBD lacks guidance on how to assign dose to radionuclides other than transuranics, uranium, activation products, and fission products. As indicated by site experts, ORNL handled almost everything on the periodic table at one point or another. There has been no screening presented to demonstrate that the secondary radionuclides (particularly accelerator- and reactor-produced) are of no dose consequence to the workers. Although ORNL handled uranium and radium in the early years, no consideration was given to occupational radon exposure. Information was not provided on the activity fractions for plutonium and thorium. Activity fractions for plutonium provide critical information for the assessment of dose from americium as an impurity. Dose from non-traditional chemical forms of radionuclides, such as high-fired oxides and tritides, were not considered. Finally, an adequate rationale for assumption of Am-241 in the case of transplutonium bioassay rather than Cm-244 was not provided.

The internal co-worker dose assignment for Ru-106, Ce-144, and Cs-137 was derived by determining their ratio to strontium on environmental air samples. The equivalency of ratios on an environmental sample to the ratios that exist in an occupational setting has not been adequately justified and limits the dose reconstructor to a site-wide ratio only.

6.1.3 Objective 3: Adequacy of Data

The completeness and accuracy of the external dosimetry data may require further verification to ensure that field-recorded dose results were integrated into OERs. The internal database currently used to determine the co-worker doses are incomplete in terms of the years covered (1947–1988). There is also an indication from ORNL records that bioassay procedures predated the first MDA presented in the Occupational Internal Dosimetry TBD (Bollenbacher et al. 2006). Data adequacy issues have been raised by ORNL workers and will require further investigations.

The Occupational External Dose TBD (Burns and Mohrbacher 2004) outlines the general beta/photon dosimetry techniques and dose reconstruction procedures for skin and penetrating doses. The TBD only provides general information concerning worker monitoring and dose data. The TBD states on page 17 that some workers were badged with experimental film before June 1944, but that these records may not be reliable. Therefore, it would appear that there is insufficient beta/photon dose data to allow dose reconstruction for workers during 1943–June 1944.

The validation and verification of the data used in dose reconstruction has not been adequately completed. There are indications that additional bioassay data exist, which are not reflected in the database obtained by ORAU for the calculation of MDAs. For example, we became aware that ORNL has not fully consolidated all the occupational exposure records, indicating that some records may not be complete. Also, the completeness and accuracy of the external dosimetry data may require further verification to ensure that field-recorded dose results were integrated into the OERs.

In summary, SC&A is concerned about the lack of verification and validation of the databases used to determine MDAs and co-worker dose. There appears to be data absent from these sources that is pertinent to dose reconstruction. There is also concern over the completeness of the hardcopy records supplied by ORNL to NIOSH. The reliance on an incomplete database and dispersed exposure records may raise questions regarding the completeness and accuracy of internal and external dose estimates. As a compensatory process, SC&A is not aware of any effort to collect bioassay data known to be absent from this database. SC&A is also not aware of any effort to independently validate its reliability by comparing the electronic bioassay results with available dosimetry printouts and forms, logbooks, air sampling data, or other sources. This type of validation and verification is recommended.

6.1.4 Objective 4: Consistency Among Site Profiles

An extensive comparison was performed by SC&A to compare and contrast the methodologies used in the ORNL site profile and other site profiles reviewed to date. These comparisons focus on the methodologies and assumptions associated with dose assessments and the derivation of values used to obtain a POC for individual claimants. A detailed analysis is provided in Attachment 5 to this report. The site description provides a comprehensive evaluation of activities that occurred at the different technical areas, and some of the potential hazards associated with these operations. This valuable data is not carried through to the other TBDs.

Overall, the default values assigned for determining medical exposure are relatively consistent among site profiles. The site profiles applie OTIB-0006, Revision 2, dated December 29, 2003, although a subsequent version was released on December 21, 2005. This version predates the issuance of Rev. 01 PC-1 of the TBD dated July 21, 2006. The later version of OTIB-0006 (Kathren and Shockley 2005) provides guidance on the assignment of dose from lumbar spin exams, which were given at ORNL. This should be corrected in subsequent revisions of TBDs. Other deviations from the standard assumptions are based on site specific information.

The ORNL Occupational Environmental Dose TBD assumes that average annual site-wide values are assigned to unmonitored workers. For LANL and SRS, the site-wide maximum ambient radiation dose is assigned when the worker location is unknown (Cehn and McDowell-Boyer 2004; Scalsky 2005). The application of multiple receptor points would be consistent with the approach in the Hanford, SRS, and Idaho National Engineering and Environmental Laboratory (INEEL) TBDs. The use of measured air concentration data is consistent with the Y-12 Occupational Environmental Dose TBD (Ijaz and Adler 2004).

With the LANL Occupational Environmental Dose TBD, a screening method was applied to the source term to determine relative dose consequences for different radionuclides. With the similarities in the breadth of radionuclides handled at ORNL and LANL, this screening method or equivalent is considered prudent at ORNL.

Review of site profiles to date indicates that the NIOSH/ORAU team has not come to a consensus on what components should be considered in the environmental dose. In the case of the ORNL Occupational Environmental Dose TBD, no consideration was given to dose from contaminated soil resuspension. It is noted that other site profiles have considered radionuclides that were present at ORNL, but not considered in the ORNL Occupational Environmental Dose TBD. The Hanford TBD included plutonium, noble gases, and MFPs (Savignac 2003). The SRS TBD included tritium, noble gases, plutonium, and uranium (Scalsky 2005). The LANL TBD included tritium, noble gases, plutonium, americium, uranium, and thorium (Cehn and McDowell-Boyer 2004). Several of the ORNL workers were stationed at the Y-12 Plant location, indicating these radionuclides may not be applicable. The Y-12 Plant handled primarily uranium, with some processing of thorium and U-233 (SC&A 2005c). These radionuclides have not been considered in the assignment of dose to workers at the Y-12 facility.

There is mention of the presence of the release radon from stacks and storage areas; however, no discussion was included for potential internal dose to radon. It would seem reasonable that radon would be present in the work place if it were being released to the environment. Radium-226 and ores were also handled at ORNL. Radon was specifically mentioned in the Mallinckrodt Chemical Works (MCW) and Fernald TBDs, where high concentrations of Ra-226 were handled. The ORNL Site Profile fails to consider radon exposure. The impact of radon on dose reconstruction should be evaluated, particularly for the early years.

During the Y-12 SEC petition review, considerable attention was given to radionuclides generated by the ORNL Isotope Production Group and potential exposures to Y-12 workers from these activities. ORNL employees were stationed at the Y-12 Plant and actively ran these

operations. The radionuclides of concern for the Y-12 Plant are H-3, Sr-90, Tc-99, Th-228, Th-232, U-232, U-233, U-236, Pu-238, Pu-239, Pu-241, Np-237, Am-241, Co-60, Zr/Nb-95, and Po-208. This is a somewhat different mixture of radionuclides than those considered for missed dose at the ORNL main site. The Occupational Internal Dose TBD (Bollenbacher et al. 2006) does not include a discussion how these are handled in dose reconstruction in terms of missed dose.

6.1.5 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 addition, SC&A evaluated the TBDs for adherence to general quality assurance policies and procedures utilized for the performance of dose reconstructions. NIOSH has complied with the hierarchy of data required under 42 CFR Part 82 and its implementation guides. As mentioned above, quality assurance with respect to claimant-specific information is lacking, and further consideration should be given to evaluating records provided by sites, and how the requests for these records are communicated to the sites. In essence, if something is not explicitly requested, it will not be provided.

6.2 USABILITY OF SITE PROFILE FOR INTENDED PURPOSES

SC&A has identified seven criteria that reflect the intent of the EEOICPA and the regulatory requirements of 42 CFR Part 82 for dose reconstruction. Because the purpose of a site profile is to support the dose reconstruction process, it is critical that the site profile assumptions, analytic approaches, and procedural directions be clear, accurate, complete, and auditable (i.e., sufficiently documented). SC&A used the following seven objectives to guide its review of the ORNL Site Profile TBDs to determine whether they meets these criteria:

Objective 1 – Determine the degree to which procedures support a process that is expeditious and timely for dose reconstruction

Objective 2 – Determine whether procedures provide adequate guidance to be efficient in select instances where a more detailed approach to dose reconstruction would not affect the outcome

Objective 3 – Assess the extent to which procedures account for all potential exposures and ensure that resultant doses are complete and are based on adequate data

Objective 4 – Assess procedures for providing a consistent approach to dose reconstruction, regardless of claimants' exposures by time and employment locations

Objective 5 – Evaluate procedures with regard to fairness and the extent to which the claimant is given the benefit of the doubt when there are unknowns and uncertainties concerning radiation exposures

Objective 6 – Evaluate procedures for their approach to quantifying the uncertainty distribution of annual dose estimates that is consistent with and supports a Department of Labor POC estimate at the upper 99% confidence level

Objective 7 – Assess the scientific and technical quality of methods and guidance contained in procedures to ensure that they reflect the proper balance between current/consensus scientific methods and dose reconstruction efficiency

6.2.1 Ambiguous Dose Reconstruction Direction

Direction provided in the site profile as a stand-alone document can be confusing, and in some cases, directions are inconsistent throughout a particular TBD. With OTIB-0034 (Kennedy 2005) for internal co-worker dosimetry data, OTIB-0021 (Merwin 2004) for external co-worker dosimetry data, and internal dose estimates for facilities with air sampling programs, the approach is somewhat more clearly defined.

The conditions for the application of environmental dose to ORNL employees are not clearly defined in the introduction of the Occupational Environmental Dose TBD, as is usually the case with other TBDs. There are recommendations for usage throughout the TBD, but concrete direction for which workers receive environmental dose is lacking.

6.2.2 Inconsistencies and Editorial Errors in the Site Profiles

Site experts identified some minor errors associated with the NIOSH TBDs.

- The description of how the tandem accelerator operates in Section 2.2.41 of the Site Description is not exactly correct.
- The dates associated with the accelerators are incorrect.
- With respect to ORELA (Section 2.2.42 of the Site Description TBD), there is one neutron-producing target in the facility. The Tantilum Radiator is actually a target.

The Site Description TBD identifies radionuclides by facility, and includes information on incidents and spills that occurred in the facilities. Some, but not all, of this information is considered in the Occupational Environmental Dose TBD (Burns 2004b) and the Occupational Internal Dose TBD. In particular, there are radionuclides (e.g., medical isotopes) that have not been included in the dose calculations. These radionuclides should be evaluated to determine their significance to environmental and internal dose.

There is discussion in the Occupational Internal Dose TBD (Bollenbacher et al. 2006) of the levels of naturally occurring environmental uranium and the ratios of isotopes. However, it is not clear how NIOSH is going to handle this with regard to levels seen in urinary and fecal excretion and the bioassay monitoring data. Section 5.2.3.3, page 19, states that, “Plots of the observed uranium excretion distributions for U-234, U-238, and total uranium are provided below.” SC&A, however, failed to find these data in the document.

The Occupational External Dose TBD states that it does not address skin exposure, yet it provides shallow dose correction factors. Furthermore, during the SC&A conference call with NIOSH, the dose reconstruction representatives indicated the shallow dose is assigned using OTIB-0017 (see Attachment 4). This appears to be providing a methodology to assess skin exposure. Clarification on shallow dose calculation is needed in the TBD.

6.3 UNRESOLVED POLICY OR GENERIC TECHNICAL ISSUES

A number of issues were identified that are common in the ORNL and other site profiles reviewed to date and, in some cases, represent potential generic policy issues that transcend any individual site profile. These issues may involve the interpretation of existing standards (e.g., oro-nasal breathing), how certain critical worker populations should be profiled for historic radiation exposure (e.g., construction workers and early workers), and how exposure itself should be analyzed (e.g., treatment of incidents and statistical treatment of dose distributions). NIOSH indicated that it may develop separate TIBs in order to address these more generic issues. The following represents those issues identified in the ORNL and previous site profile reviews that, in SC&A's view, represent transcendent issues that need to be considered by NIOSH as unresolved policy or generic technical issues.

(1) Direction on the applicability of the TBD and/or TIBs to individual dose reconstructions is absent.

(2) Mobility of work force between different areas of the site should be addressed. Site expert testimony that many workers moved from one plant to the next is a complicating factor. Establishment of an accurate worker history is crucial in such cases. This will be especially difficult for family-member claimants.

(3) Statistical techniques used in the application of the data to individual workers should be further considered and substantiated.

(4) Dose from the production of less predominant radionuclides from accelerator- and reactor-activation activities.

(5) Dose from impurities and/or daughter products in radioactive material received and processed at sites should be assessed as a contributory exposure source.

(6) The significance of various exposure pathways and the assumptions made that influence dose contributions need to be considered (most notably) for solubility, oro-nasal breathing, and ingestion.

(7) Analysis needs to be performed regarding how "frequent or routine incidents" should be addressed, given the possibility that such "spike" exposures often may be missed by routine monitoring as a function of how often and in what manner it was conducted.

(8) Availability of monitoring records for "transient or outside workers," e.g., subcontractors, construction workers, and visitors, who may have potential exposure while working on or visiting a facility should be ascertained.

(9) Dose to decontamination and decommissioning (D&D) workers should be assessed. Many facilities have large-scale D&D operations, which extend back many years. Decontamination and decommissioning operations often require working in unknown situations, which may provide unique exposure situations.

(10) Dose from non-traditional chemical forms of radionuclides, such as high-fired oxides and tritides, requires evaluation.

(11) Dose reconstruction for occupational medical exposures remains incomplete. NIOSH needs to reconsider the definition to include all forms of medical radiation exposure to ensure its considerations are claimant favorable.

(12) Dose reconstruction for workers involved in nuclear weapons testing who were employed by a site other than the test site.

(13) Quality Assurance on records provided by the site to the NIOSH/ORAU team is necessary to ascertain whether complete information is being provided.

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ATTACHMENT 1: NIOSH TECHNICAL DOCUMENTS CONSIDERED DURING THE REVIEW PROCESS

Technical Basis Documents

ORAUT-TKBS-0012-1, *Technical Basis Document for Oak Ridge National Laboratory – Introduction Rev. 00,* August 11, 2004 *(*Burns 2004a).

ORAUT-TKBS-0012-2, *Technical Basis Document for Oak Ridge National Laboratory – Site Description Rev. 01*, August 30, 2006 (Fleming 2006b).

ORAUT-TKBS-0012-3, *Technical Basis Document for Oak Ridge National Laboratory – Occupational Medical Dose Rev. 01 PC-1*, July 21, 2006 (Fleming 2006a).

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ORAUT-TKBS-0012-5, *Technical Basis Document for Oak Ridge National Laboratory – Occupational Internal Dose Rev. 00 PC-1,* May 30, 2006 (Bollenbacher et al. 2006).

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ORAUT-OTIB-0017, Rev. 01, (2005), *Technical Information Bulletin – Interpretation of Dosimetry Data for Assignment of Shallow Dose*, Oak Ridge Associated Universities, Oak Ridge, Tennessee, October 11, 2005 (Merwin 2005).

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ORAUT-PROC-0060, *Occupational Onsite Ambient Dose Reconstruction for DOE Sites,* Oak Ridge Associated Universities, Oak Ridge, Tennessee, June 28, 2006 (Winslow 2006a).

ORAUT-PROC-0061, *Occupational X-ray Dose Reconstruction for DOE Sites,* Oak Ridge Associated Universities, Oak Ridge, Tennessee, June 21, 2006 (Winslow 2006b).

ATTACHMENT 2: SITE EXPERT INTERVIEW SUMMARY

<RESERVED>

ATTACHMENT 3: KEY QUESTIONS AND RESPONSES FOR NIOSH/ORAU REGARDING SITE PROFILE DOCUMENTS

SC&A submitted questions related to the ORNL Site Profile documents to NIOSH on August 1, 2006. The NIOSH/ORAU team provided written responses to these questions on August 25, 2006. Both the questions and responses have been provided below. A summary of the conference call conducted between SC&A and the NIOSH/ORAU team with regard to these questions is presented in Attachment 4.

Questions and Responses

Site Description (ORAUT-TKBS-0012-2)

(1) How will potential exposures to site personnel from unfiltered emissions be handled for claimants? Page 21 of the Site Description TBD, ORAUT-TKBS-0012-2, says that airborne exhausts from B 3001/3018 did not include a filter system before 1948. Later they found particulates still airborne from fuel slugs pushed out back of the reactor. Also, gaseous wastes, such as noble gases Ar-41, Xenon/Krypton, and radioiodines, were not filtered or quantified.

These issues are addressed in the onsite environmental TBD.

Airborne wastes were removed from Building 3001 and exhausted to the atmosphere from a 200-ft stack (Building 3018) immediately north of the Graphite Reactor Building…..

> Airborne wastes were removed from Building 3001 and exhausted to the atmosphere from a 200-ft stack (Building 3018) immediately north of the Graphite Reactor Building. Initial design of the exhaust system did not include a filtering mechanism. By 1948, it was recognized that radioactive particulates were being emitted from the stack. Particulate filtration was added to reduce the emissions. Researchers later discovered that particulate contamination became elevated in the airborne effluent stream when fuel slugs, pushed out the back of the reactor, would fall and strike the mattress plates. The impact would sometimes breach or further breach the aluminum cladding, resulting in a release of particulate matter into the air. The large building ventilation fans would entrain these particles and exhaust the particles out the stack. Therefore, concentrations of gaseous wastes such as noble gases (^{41}Ar and several xenon/krypton isotopes) and radioiodines were not filtered and were not quantified.

(2) Have interviews been conducted with workers at the Y-12 ORNL Biological Sciences division to determine if any problems with sources occurred? (See pages 29 and 30 of Site Description ORAUT-TKBS-0012-2).

Information of this nature is gleaned through the Computerized Assisted Telephone Interviews (CATIs), which seeks input from claimants and Worker Outreach process, which seeks input from all workers and former workers, claimants and potential claimants. The TBD team did not seek out workers individually.

(3) How is dose reconstruction going to be possible for numerous buildings where the dates of operations and processes are not even known? (See page 26 of the Site Description, ORAUT-TKBS-0012-2). This could be an issue when the site relied on the area health physicists to determine if in-vitro bioassay monitoring and in-vivo monitoring should be done, and appears only to be done if there were known spill/incident, or air and contamination sample results that indicated it should be done, yet the dates of different operations in the areas is not known.

Available information including individual information regarding individual bioassay and information from the CATIs is being used to reconstruct doses. When a dose reconstruction warrants, coworker bioassay will also be considered. Because the bioassay data were collected in response to incidents or at times when results would likely be the larger, their use in coworker models and chronic exposure scenarios is considered claimant favorable. (The site description section is not meant to be the guide for how dose reconstructions will be done, rather it is provided to describe the sites chronological activities and source terms that are important to understanding the opportunities for employees to incur radiation exposure.

Occupational Medical Dose (ORAUT-TKBS-0012-3)

(1) The Occupational Medical Dose TBD, ORAUT-TKBS-0012-3 (Fleming 2006a) states in the introduction, in Section 3.1, that all internal and external dosimetry monitoring results are considered as part of a valid dose reconstruction. However, it excludes radiation from radon and its daughters, and any radiation from diagnostic x-rays received to treat work-related injuries. Explain the procedures that NIOSH plans to adopt to subtract such radiation dose when the dosimeter was inadvertently exposed during x-ray procedures, or due to naturally occurring radiation exposure in the workplace?

This passage in the TBD has not been accurately summarized. Note that exposure from naturally occurring radon in conventional structures [and the environment] are not considered "occupationally derived." (Radon is an issue for the environmental or internal dose section.) Unless information is available that specifically indicates that a dosimeter's reading was due to non-occupationally derived exposures, no attempt would be made to adjust the reported result for this possibility. Such instances would be handled on a case-by-case basis. To date, we are unaware of dosimeters being identified as worn during medical examinations and used to monitor occupational work radiation doses.

(2) The TBD (Fleming 2006a) in Section 3.2 states that preplacement, annual, and termination examinations are all contributors to the occupational medical dose, as defined under EEOICPA. Would NIOSH define the nature and type of diagnostic x-rays that constitute "annual" examinations? Would NIOSH also explain and clarify whether periodic screening exams, such as for TB or qualification screenings for respirator certification and asbestos workers, constitute annual exams?

Occupationally required (versus medically required) x-rays are included in dose reconstruction. Periodic occupationally required screening X-ray exams that are performed because of statute or policy, and that are not based on an employee's individual need for diagnosis are generally considered to be in this category, and the SC&A examples of screening exams for TB, respirator certification, and asbestos work fit this category.

(3) The TBD (Fleming 2006a) in Section 3.3 indicates that exams required as a "condition of employment" only are covered. Could NIOSH further define and clarify what constitutes a "condition of employment?" Most x-ray procedures are given on a voluntary basis, such as routine annual chest x-rays. Does this constitute a "condition of employment?"

The phrase "condition of employment" comes from 42 CFR 81, where there is a little more context to the phrase. 42 CFR 81 states that "Additionally, some employees covered by EEOICPA were required, as a condition of employment, to undergo routine medical screening with x-rays. The dose resulting from these x-rays will be included in their dose reconstruction."

The ORAUT has used an OSHA definition of medical screening as tests performed on asymptomatic persons, without history or complaint. We try to research the site's documents to uncover screening protocols, study claim files to determine exam frequencies, and search open literature for common practices for comparable time periods in order to determine which x-ray procedures and projections should be considered screening for a particular DOE site.

(4) The TBD states in Section 3.3 that photofluorographic (PFG) exams were used only for preplacement screening from 1943 through October 3, 1947. The TBD infers that only one PFG exam was given to each new employee. However, available historical documents indicate that multiple uses of PFGs over several years were given to some employees. If the doctor requested further exams, a follow-up regular chest x-ray was also given. Would NIOSH clarify how the dose reconstructor ought to consider cumulative dose from PFG exams, particularly for claimants who worked during 1943–1947?

Page 11 of the current TBD indicates that a stereoscopic PFG for pre-placement should be assumed for individuals who began employment at ORNL from 1943 through 1947, and that documented retakes, routine annuals, and terminations that may have occurred during that time period would have been a 14-in x 17-in radiographic PA images provided at the Oak Ridge Hospital.

A sample of about 15% of the entire set of PFGs located at ORNL were reviewed, and in only one instance was an individual found to have received more than one PFG, and these were taken one year apart. While additional PFG sets may exist for an individual, it appears that this was not the norm.

(5) The TBD in Section 3.4.1 discusses the peak applied voltage and filtration used in the Picker Model R-2 installed in October 1947. The TBD indicates that the medical staff asserted that the inherent filtration was 0.04 mm of aluminum (Al). Further review of historical documents suggests that the 0.04 mm Al value is actually derived from surveys of the unit by R.L. Tuck in 1956 and 1957, and appears to be in error. Later measurements, taken by E. Gupton in 1957, provide an assumed value of 1.0 mm Al, with no basis being given. Could NIOSH clarify the actual filtration for this unit? The importance to be associated with this question is that the entrance skin exposures from a PA chest of 21 mrad may be incorrect if the assumed filtration and half-value layer (HVL) is in error.

Though it is acknowledged that the filtration provided by Mr. T. L. Tuck both in 2003 and documented on several surveys conducted in the mid-1950s for the Picker Model R-2 unit used at ORNL was 0.04 mm of Al, this filtration value does not appear to be reliable. On those same "historical documents" referenced above, the measured skin dose was 25 mrad at ORNL. Also in the two peer-reviewed reports written by T. A. Lincoln and E. D. Gupton that "assume" a 1.0 mm filtration, the measured exposure to the skin at ORNL for a PA CXR was 21 mrad. Both these measured values are less than the entrance skin exposure (56 mrad) used in the TBD to estimate organ doses and as indicated in the footnotes to Table 3-4, "This value is approximately a factor of 2.7 greater than that measured and is claimant favorable." Based upon a comparison of the measured vs. calculated ESE values, using a filtration of 1.0 mm Al is favorable to the claimant.

(6) The TBD in Section 3.4.2 states that PFGs were not performed at the ORNL medical facility. What we need to know is if any employees were sent to the Oak Ridge Hospital for chest radiography either as preplacement or annual exams after October 1947? Has NIOSH identified when the PFG unit was no longer used at the Oak Ridge Hospital? Other documents referenced in the TBD (Lincoln and Gupton 1958a) and (Lincoln and Gupton 1958b) suggest that employee x-rays may have occurred at two hospitals, two local radiology offices, and other Oak Ridge sites. Can NIOSH establish whether other facilities may have had PFG units other than Oak Ridge Hospital?

The reviewed information did not indicate ORNL employees received preplacement or annual chest exams at Oak Ridge hospital after October 1947. The date for discontinuance of the PFG unit at the hospital and whether PFG units were used at other locations is currently irrelevant to the ORNL TBD and dose reconstructions, given these facilities were not used for the occupationally required medical x-rays. The Lincoln and Gupton articles do not indicate that ORNL's occupationally required medical x-ray examinations were made at 2 hospitals, 2 radiology offices and other Oak Ridge sites, rather they state that these researchers wanted to account for all x-ray doses received by the ORNL population. A review of the articles confirms this as doses from exam-types that are not associated with occupational requirements, such as abdomen and knee exams, are tabulated in the articles.

(7) The TBD in Section 3.4.4 states, according to a long-time radiology technician, that x-ray beams at ORNL were always well-collimated. However, later in Section 3.5, the TBD states that lead-lined gonad shields were used at ORNL until they were discontinued in favor of collimation of the beam. Could NIOSH clarify this apparent discrepancy in the TBD?

Reviewer is directed to the discussion on page 10 that describes this issue. Though NIOSH had verbal (from the radiological technician) and documented (20 cm cone shield from the Lincoln and Gupton papers) information that the medical radiographic equipment was well collimated, poor collimation was assumed until 1963. This decision by the ORAUT was based on an analysis of organ doses in a table in the Lincoln/Gupton papers. The TBD states the results of this analysis "indicate that the dose conversion factors (DCFs) given in ICRP 34 for a well collimated beam may not apply and therefore uncollimated DCFs found in ORAUT-OTIB-0006 … were used until a newer x-ray unit was procured in 1963. Table 3-3 also indicates that in the assumed operating parameters to "Use uncollimated DCFs for organ dose estimates for the Oak Ridge Hospital and Picker units. Collimation of the beam for the Westinghouse and Bennett units is assumed to be good and ICRP 34 values used." Though information obtained from the site indicates that the beam was collimated, the decision of using DCFs from uncollimated beams has some bases and is favorable to the claimant.

(8) The TBD in Section 3.5 states that dose reconstructors need only consider chest PA and LAT x-rays, and the lumbar spine series (4 films) in a claimant dose reconstruction. As also evidenced in Table 3-2, it appears that all dose calculations prior to 1996 are to be based on a PA chest view only and not a LAT. Can NIOSH clarify and document that annual chest exams did not include a LAT view, unless specifically prescribed by the physician?

The information that was provided by ORNL and limited x-ray films that were reviewed indicated that chest x-rays were conducted until April 18, 1996 with one PA projection. Table 3-2 indicates date ranges, techniques utilized, and what people were involved in the medical x-ray program at ORNL. The table identifies PFG chest x-rays, conventional PA chest x-rays, lumbar spine series, and lateral chest x-rays that were given at ORNL. This information was provided to NIOSH from ORNL.

(9) The TBD in Table 3-2 lists the type of equipment and frequency of exams. The table indicates that chest radiography was only provided as a preplacement requirement after 1963, and annual exams were not required. Can NIOSH clarify this table, relative to statements in the TBD that annual chest x-rays were only required until 1970, after which they could be waived? Can NIOSH document that respirator program employees only required an exam every 3 years after 1976?

The text indicates that the annual and termination X-ray examinations were provided into the 1970s; although there are inconsistencies among the text, Table 3-2 and Table 3-4, dose reconstructors are assuming preplacement, annual and termination examinations through 1976. The reference regarding the X-ray examination requirement for respirators workers, Ref ID 10114, can be found in the SRDB.

(10) According to other historical documents, it appears that extra doses may have resulted from lining up several employees inside the x-ray room to await annual x-rays. Has NIOSH attempted to estimate these potential extra doses to workers who were exposed by this practice?

If such a practice did occur, the exposure from scatter of the beam, which would have been much smaller (probably on the order of 1% or less), would be adequately accounted for in the uncertainty assignments associated with reconstructing x-ray doses.

Occupational Environmental Dose (ORAUT-TKBS-0012-4)

(1) Could NIOSH refer to the instructions or guidelines used to reconstruct missed environmental doses? We recognize that Attachments 4A, 4B, and 4C provide annual airborne release data, annual average airborne concentration and intake data, and annual average site-wide exposure rates data.

Environmental doses are only used to estimate doses for unmonitored workers, who would not have required radiological monitoring. We are not sure exactly what the question is; we are not aware of what "missed" environmental doses are being questioned. The only missed dose mentioned in this TBD is for external dose and this doesn't appear to be the issue. Please clarify question.

(2) Could NIOSH clarify how they plan to identify and deal with those potential unmonitored workers that may receive missed environmental doses? Are they identified by their working location or job title? Are there monitored workers who would leave their TLD in their working location before they left ORNL site? Were the monitored workers required to receive whole-body counting and bioassay testing routinely (weekly monthly, and quarterly)? If not, how do we know whether these monitored workers received missed environmental doses?

OTIB-0014 gives guidance for determining when to assign environmental intakes rather than internal dose.

Environmental doses are assigned for unmonitored exposures. If bioassays or other monitoring records provide indications for a given type of radiological exposure, the assignment of dose based on environmental estimates is not appropriate. Therefore the questions regarding bioassays are considered irrelevant in the context of this question.

It is unclear what "missed" environmental dose means. Workers who have no monitoring may or may not be identified by location or job title. Where monitored workers left their dosimeters is not relevant to the Occupational Environmental Dose TBD. Bioassay information for monitored workers is addressed in ORAUT-TKBS-0012-5).

Regarding environmental dose assignments for unmonitored employees, the maximum of the site wide annual median environmental intakes, which includes a favorable to the claimant assumption of 2000 hours of exposure at the maximum of the annual median air concentrations is used to estimate unmonitored worker internal doses. This maximizing approach is sufficiently large to address any "missed" internal dose.

(3) We suggest that in future updates to the Occupational Environmental Dose TBD (Burns 2004), a section that addresses accidental spill of radioactive material or waste and how the dose reconstructor would determine a dose to involved workers? Could there not be a source of missed environmental dose to workers by way of contaminated soil - windblown of resuspended contaminated soil?

The environmental section of the TBD is used to assign dose to workers who would not have been subject to site and regulatory monitoring requirements, so these workers' involvement in spills would not be routine. Any airborne contaminated soil would have been indicated by the onsite air sampling network. Information on spills and the like is included in the site facilities TBD.

(4) Could NIOSH comment on potential dose that might be expected from worker exposure when working around evaporation ponds or cooling ponds? The Occupational Environmental Dose TBD (Burns 2004b) mentions the presence of the settling basin that contributed to the missed environmental dose to workers, but there is no mention of evaporation ponds or cooling ponds.

It's not clear what evaporation/cooling ponds this question refers to.

(5) Has NIOSH considered dose reconstruction for exposure received during uranium ore processing, ore contamination, tailing piles, or airborne dust concentration data from the ore processing?

Although we recently learned that the uranium ore and residues and scraps from uranium operations were stored in at least two of the warehouses at the Clinton Lab, it is not clear that any uranium processing was taking place (there was mention of a rebagging process) or that uranium ore tailings piles were onsite. Further investigation of this source term will be pursued for reconstructing dose.

(6) Has NIOSH considered the impact of waste piles and waste drums as potential sources of exposure in the Occupational Environmental Dose TBD (Burns 2004b)?

If there were such collections of waste which contributed to the ambient exposure rate at X-10, currently they are considered addressed via the monitoring data used in the TBD.

(7) Did NIOSH identify other important sources of environmental exposure, other than airborne releases from stacks and reactors referenced in Burns 2004b? Also, would NIOSH explain how they plan to provide guidance to the dose reconstructor for these additional sources of environmental exposure?

The current TBD addressed what we believed to be the major contributors to exposure, but as additional information becomes available and if it indicates modifications are warranted, information will be added to the TBD for use by dose reconstructors.

(8) Could NIOSH provide clarifications on the reasons for not including any discussion or any detailed uncertainty analysis of airborne concentration data and exposure data? Have these uncertainties been quantified and are they utilized in doing environmental dose reconstructions?

Uncertainties in the form of geometric standard deviations are asserted in the attachments summarizing the exposure data. A default GSD = 3 is assigned to environmental doses.

(9) The Occupational Environmental Dose TBD (Burns 2004b) indicated that the annual "average" airborne concentrations and annual "average" exposure rates are “bounding” values. The TBD, however, indicated that these site-wide average data might not be appropriate for cases in which a composite exposure profile for an unmonitored individual is inconsistent with a known or asserted exposure history. Would NIOSH then explain why these site-wide average data can be considered to be “bounding?” Is there a more claimant-favorable way to deal with this?

This is explained in the TBD. The method used is believed to be extremely favorable to claimants since it includes contributions from sources in areas which should have been off-limits to unmonitored persons. Monitoring data from more remote locations (which in reality are likely more indicative of the exposure to an unmonitored individual) were not included in the averages, resulting in a high (favorable) bias.

(10) Some location-specific data were not provided in the TBD. For example, on page 33 of the Occupational Environmental Dose TBD (Burns 2004b), specific site locations (e.g., 706 D) were not provided for use by the dose reconstructor. Would NIOSH provide the location of these data? And clarify how can a dose reconstructor find these data to use in the dose reconstruction efforts?

The data appear in the routine HP Division progress reports and similar documents and dose reconstructors have access to TBD authors if they need

assistance in locating site data. Keep in mind these locations were inside the protected area and thus should not have been accessible to unmonitored workers. However, specific locations of workers are not known, so the citation of specific areas does not generally provide the DR with information that can be applied to a particular case.

(11) The Occupational Environmental Dose TBD (Burns 2004b) focuses on onsite airborne I-131 concentration, onsite airborne concentration of mixed fission products (MFPs), onsite airborne concentrations of tritium, and onsite exposure rate data. Are there any MAPs from the different reactors?

These are included in the MFP data, which are gross beta. MFP should probably be changed to mixed fission/activation products (MFAP).

(12) Why has NIOSH chosen the breathing rate of 1.2 m^3/hr? Is that value claimant favorable for maintenance workers and movers?

The chosen breathing rate is standard for routine analyses, and when combined with other assumptions in the TBD (2000-hour exposures at the maximum of the median annual intake rates), we believe the resulting intakes estimated for unmonitored workers are claimant favorable. The issue of breathing rate is a programmatic issue and not a site profile issue.

Occupational Internal Dose (ORAUT-TKBS-0012-5)

(1) How would NIOSH plan to handle dose reconstruction for the large numbers of unmonitored workers up through the 1970s, 1980s or maybe even 1990s?

On page 11 of the ORNL Internal Dose TBD (Bollenbacher et al. 2006), the TBD notes that "*urine samples were collected in the early years of the bioassay program based on the area health physicist's knowledge of field conditions (e.g., known spills/incidents, air and contamination sample results, etc.). This practice of scheduling did not utilize a specified sampling frequency (Auxier 2004; Henley 2004).*" It is further noted on page 21 that "*Although several located documents stated that baseline and specified monitoring frequencies were utilized to make in-vivo measurements, Berger (2003) and McLaughlin (2004) indicated that a full in-vivo monitoring program did not exist at ORNL until approximately 1994, when site internal dosimetrists became responsible for identifying personnel for counting.*" This practice for determining sampling for both in-vitro and in-vivo monitoring throughout the history of the site up through the 1980s or even 1990s raises a serious question of unmonitored workers with potential for uptakes. The issue is further exacerbated in Table 5-3 (page 11), which states that these sampling frequencies should be followed, but the text notes that these may not have been followed. Table 5-3, last row, also notes for "*All others – Consult w/Internal Dose Group.*" What was used for the hundreds of other radioisotopes?

This issue is present at almost all sites. For long-lived nuclides, routine (i.e., samples collected frequently on a specific schedule) are not necessary for performing a bounding dose reconstruction; the material is retained long enough that a few samples can provide enough information. For gaps after the last bioassay sample or for shorter lived nuclides, coworker data would be used.

(2) Clarify NIOSH's approach in determining tritium exposure. Tables 5-1 on page 10 notes over 2,000 samples were analyzed. Were there tritides involved or handled at ORNL? There is no discussion of this potential for exposure or guidance to the dose reconstructor.

At this point it is not clear if metal tritides were handled at ORNL, and if they were what quantities and what processes were involved. In general tritium tritide contributes little dose unless there are large quantities of contamination found in the work place. Currently tritium dose is calculated and assigned assuming exposure to HTO whenever monitoring for it is found in the dosimetry record. Additional information regarding ORNL tritium use will be sought.

(3) How is NIOSH going to deal with the conflicting assumptions for solubility classification for uranium? The ORNL Internal Dose TBD, ORAUT-TKBS-0012-5, states that the default should be Type S (page 67), however, the LANL Internal Dose TBD, ORAUT-TKBS-0010-5, recommends using Type M. The ORNL Internal Dose TBD does not address the Integrated Modules for Bioassay Analysis (IMBA) NIOSH Phase I database USDOE Version 1.0.42, Tables 5-11 and 5-12 for isotopic composition for uranium. Why not?

No citation on page 67, stating the uranium default absorption type is type S, was located. Dose reconstructors are assuming ORNL exposures were to type F, M, or S uranium, and the selection is based on claimant favorability (Section 5.1.2 of the TBD). The TBD provides site specific information and not information on dose reconstruction tools, like IMBA (not a database), which are addressed in other documents or guidance; however, this question might be referring to enrichment assumptions for uranium at ORNL. For uranium bioassays, where measurements were based on gross alpha counting, knowledge regarding the enrichment is not needed to reconstruct dose.

(4) The ORAUT-TKBS-0012-5 TBD, Section 5.2.3.3, page 18, talks about the environmental uranium, but I cannot find any reference to the fact that it was subtracted from the bioassay results. Were the background uranium values subtracted from the bioassay results?

These data didn't exist until the 1990s and are apparently used by ORNL for an indication to investigate suspect uranium results. It does not appear they were used for the purpose of background subtraction. There is no indication that estimates of environmental uranium in urine were subtracted from bioassay

results reported by ORNL and such an adjustment is not being made in this dose reconstruction project.

(5) The ORNL TBD (Bollenbacher et al. 2006) discusses background environmental uranium and fallout Cs-137, but there is no mention of a problem or issue of radon or radon daughters. How were these handled by the dosimetrists? What kinds of exposures to these occurred and are they accounted for by the NIOSH dose reconstructors?

Radon and radon progeny interference is typically not an issue for internal dosimetry measurements (although it might be a consideration during design and set up of counting installations, as well as determination of parameters related to determining detection thresholds). Occupation radon exposure information for ORNL will be gathered for incorporation into the site profile; see response to Question 6 of this section.

(6) Early documents (Memoranda to Col. Stafford L. Warren, March–June 1944, by John Ferry, et al.) certainly indicate that radon and radon daughters were an issue for the ORNL site. How are the unmonitored exposures to these radionuclides going to be dealt with by dose reconstructors? There is no reference or discussion of this problem as a potential internal exposure issue in the ORNL Internal Dose TBD. This has been an issue of concern at most all other DOE sites.

From available references, it appears that measured radon levels in 1944 ranged from 240 to 7276 pCi/L in storage warehouses (2 and 3) that contained uranium ore at the Clinton Engineer Works 0101 area. We agree that radon exposures need to be addressed in the ORNL TBD and certain dose reconstructions.

(7) Information provided on page 9 (Bollenbacher et al. 2006), Section 5.1.1, and on page 12, Section 5.1.5, is somewhat confusing. It is stated on page 9 that, "*Table 5-1 lists radionuclides included in in-vitro bioassay results provided by ORNL for the period from 1947 to 1988,*" and further points out on page 9 that "*These values do not reflect the total number of in-vitro bioassays performed by ORNL in this period, because not all hard-copy records are in the database.*" Page 11 states that, "…ORNL has entered <u>much</u> historical *in vitro* monitoring data into a database." Table 5-1 has numerous radionuclides listed with sample sizes of 1 to 10. With all the hundreds of radioisotopes handled at ORNL, as noted on page 30 of the Site Description TBD, ORAUT-TKBS-0012-02, how many *in-vitro* bioassay samples for these hundreds of radioisotopes really exist? (Emphasis added.)

The reference to page 30 of ORAUT-TKBS-0012-2, which includes mention of 250 isotopes, is in a paragraph that includes description of the Stable Isotopes Program, and the number 250 does not refer only to radioactive isotopes, but includes both radioactive and stable isotopes. We have a database of all of the results, if this information is needed. However, this question does not appear germane to dose reconstruction.

(8) What guidance is given to dose reconstructors regarding Am-241 exposures? The TBD Section 5.2.3.1, page 18 (Bollenbacher et al. 2006), notes that, *"…monitoring of transplutonium elements was unable to differentiate between such nuclides as ^{241}Am and ^{244}Cm. The default radionuclide to use with measurements involving trivalent alpha actinides would be ^{241}Am. The detection sensitivity of the transplutonium analysis technique is not well documented for samples processed before 1985."* This seems like a weak approach considering Cm-244 was handled as a radionuclide. There is likewise no discussion of the ingrowth of Am-241 and the issues it presents in using in-vitro and in-vivo monitoring for internal dose reconstruction. Table 5-10 (page 17) includes Am-241 in the sequential analysis; however, americium should not be inferred as being absent without the presence of plutonium. Also, when plutonium mixtures are present, the absence of americium above detection levels should not preclude the calculation of dose from americium contribution to the mixture. The TBD does not appear to address the issue of missed dose from americium.

Because the TBD gives no guidance on plutonium mixtures, the DRs don't include Am in the Pu intakes; it would only be included if there were Am results. According to Dave McLaughlin (ORNL internal dosimetrist) who said they make no such assumptions either – they treat Pu and Am independently because they have Am sources unrelated to Pu. However, it would be helpful to know whether weapons-grade, fuel-grade, or no specific Pu mixtures are being used.

(9) Bioassay sampling in early years, before routine sampling was formalized, depended on area health physicists' decisions based on spills, incidents, and air and contamination sample results. Many of the radioisotopes in Table 5-1 (page 10) have less than 10 samples recorded, and this is only a small fraction of the more than 250 radioisotopes noted on page 30 of the Site Description TBD, ORAUT-TKBS-0012-2. What are dose reconstructors to do for these poorly recorded radionuclides? Or, can it be proven that no potential for exposures occurred for the radionuclides? Certainly there were indications that some contaminants got to the environment, as noted in the Site Description, and it is hard to imagine that none of the workers received exposures.

As noted in response to Question 7 of this section, the Site Description TBD referred to 250 isotopes, not 250 radioisotopes. Not all of these isotopes are radioactive. It's not clear what a poorly recorded radionuclide is. Given that there are bioassays, and that monitoring may be indicative of a potential for exposure, a conclusion of no exposure potential cannot be drawn for all workers, although for many workers this might be the case. For the early years, the TBD page change that provides instruction to use ORAUT-OTIB-0018 addresses exposure to mixed source terms.

(10) What are the boundary conditions for chronic intakes of radionuclides? The Internal Dose TBD does not address this issue or the maximum allowable concentrations (MAC) for potential missed dose calculations. A method for identifying workers and assigning missed dose for those potentially exposed to all the assorted radionuclides for which MDAs have been determined is lacking in this document. Likewise, for all the other

radionuclides, such as those produced by the ORNL Isotopes Production Group, a method is also lacking for assigning a missed dose.

It would not be reasonable to assign missed dose (estimated from the detection threshold of the monitoring result for an individual) from all the radionuclides listed to all potentially exposed workers who did not have associated bioassay. For many of the listed radionuclides, the amounts and periods of use were limited and the associated dose conversion factors. Where there is evidence that monitoring should have occurred for a particular radionuclide and a particular claim, the dose from the particular radionuclide is reconstructed by the dose reconstructor, or the method of estimating internal dose is sufficiently favorable to the claimant that the dose is adequately accounted for, or the additional dose is ignored because it will not influence the compensability decision.

(11) The ORNL Internal Dose TBD (Bollenbacher et al. 2006) does not address or consider potential exposure from the ingestion pathway, especially in the early years. Many of the radionuclides handled at ORNL were highly soluble. What guidance will be given to dose reconstructor for calculating this missed dose?

Bioassay is an indicator of all modes of intake and the assumption of inhalation intakes (when no specific information is available, and which include a portion of ingested material in the inhalation model) is generally a claimant-favorable assumption, and adequately addresses dose, especially when distributions are assigned to account for uncertainty in the modeling. For doses derived from air concentrations in the workplace an ingestion dose would be estimated in accordance with NIOSH guidance.

Missed dose (the dose that is missed because detection capabilities related to the specific item being monitored) is assigned by dose reconstructors according to generic project guidance. We believe this question might refer to unmonitored individual dose. For the early years, intakes are estimated using the ORAUT-OTIB-0018 approach as identified in the ORAUT-TKBS-0012-5 Rev 00 PC-1. A coworker model is also available for estimating dose in ORAUT-OTIB-0034. Because both of these models are believed to be sufficiently generous in assigning dose to their intended population, workers who were unmonitored, ingestion is not specifically included.

(12) Will some of the processes involved at ORNL be treated as high-fired Super S forms of plutonium? It is stated on page 17 and 22 of the Site Description TBD, ORAUT-TKBS-0012-2, "*The Fuel Cycle Alpha Facility (FCAF) fabricated PuO and (Pu,U)O fuel pellets and was used for coating sol gel-derived microspheres with pyrolytic carbon.*" This occurred in B 3019 and 4508. It is also noted that gloveboxes were equipped to synthesize, press, and sinter pellets of Pu and U nitrides in B 4508.

Assumption of absorption types is considered a generic dose reconstruction issue. The site profiles identify the radioactive materials and associated processes, so

appropriate absorption types can be determined and applied by dose reconstuctors. It appears that when guidance for assigning super S plutonium intakes is finalized, at least some ORNL dose reconstructions will be impacted.

Occupational External Dose (ORAUT-TKBS-0012-6)

Monitoring

(1) Page 11 (Burns and Mohrbacher 2004) – It is stated that workers required to work in restricted areas more than 3 days per week were assigned beta-gamma monitors. Do the workers who only worked in restricted area 1 or 2 days per week have any dose of record? Could a worker work in numerous different restricted areas 1 or 2 times each week, and not be monitored because he/she did not work in any given restricted area more than 1 or 2 days in a week?

Early exposure limits were based on daily (0.1 R/day) or weekly (0.3 R/wk) limits and typically monitoring of workers expected to exceed perhaps 10% of these limits. There is little distinction between assigning pocket dosimeters to workers routinely entering restricted areas and workers using so-called "trip dosimeters", i.e., those issued on an ad hoc basis, whenever there is an occasional entry into a restricted area.

(2) Page 11 (Burns and Mohrbacher 2004) – The last paragraph states that as of 1951, all regular workers were required to wear a combination security badge and film dosimeter. Did this include NTA film in all cases?

The design of that badge had the NTA film behind the beta/gamma film, and often a positive result greater than a defined level on the more easily processed beta/photon film was a pre-requisite to processing the NTA, so yes, the NTA was normally present. It wasn't always processed, however. Neutron dose is assigned using the guidance in the technical basis document, using recorded results and neutron:photon ratios. Due to dosimetry limitations, both are discussed in the TBD and used in dose reconstruction.

(3) Page 17 (Burns and Mohrbacher 2004) – It is stated that zero and blanks do not mean the same thing on the individual data cards as they do on the computer system(s), and it is recommended that the dose reconstructor use the individual data cards if available. Are these data cards frequently available? Please discuss how zero and blank entries are handled during DR, especially as dosimetry/recording systems changed throughout the years.

A review of the NOCTS files indicates the cards are routinely available, even in the years when the computer printouts are also included. Dose reconstructors assign a missed or estimated dose using OCAS-IG-001 guidance whenever there is not a positive recorded dose for a routine exchange period, and it is believed likely that the individual was incurring exposure.

(4) Pages 60 and 61 (Burns and Mohrbacher 2004) – The maximum readable dose on gamma films was set at 5 R to 20 R. How were doses assigned for workers whose films were blackened? Did this occur very often?

Some records contained evidence of blackened films. The technician selected and recorded various codes when this happened (valid exposure, light leak, water intrusion, etc.). The ORNL HPs then performed an investigation and assigned a dose. This documentation is included in the workers' records.

Non-penetrating radiation doses

(1) Page 12 (Burns and Mohrbacher 2004) – It is stated that ORNL did not report skin (or superficial) dose until the second half of 1961. How will skin, breast, and testes DR be performed for 1943–1961?

The open window (OW) data should be used in assigning dose. Those dose quantities were not used prior to 1961, but that does not mean that data were not available to make an evaluation.

(2) Page 19 (Burns and Mohrbacher 2004) – Beta dosimetry is mentioned in Section 6.3.3.1, which discusses some shortcomings/unknowns in the early years. Has any effort been made to identify and list the major job titles and/or locations where beta exposures should be of particular concern during DR?

No, dose reconstructors routinely use information provided in the respective claims, in the claimant interviews, and in the DOE provided dose records to evaluate significant parameters potentially impacting dose reconstruction. As noted in the TBD, a quantitative assessment of workplace beta and photon radiation fields has not been located. As such, the dose reconstructor has little option but to assume favorable to the claimant values.

Neutron doses

(1) Page 16 (Burns and Mohrbacher 2004) – Table 6-2 lists NTA film in routine use around 1949. How will neutron DR be performed for 1943–1949, if neutron dose information does not exist to determine n-p values for that period?

This issue was recognized when the TBD was developed and is one reason to select the use of a neutron-to-photon (n:γ) ratio approach to assign neutron dose. The intent of the TBD guidance was to provide n:γ dose information for ORNL reactors so dose reconstructors could apply these ratios to the early time period

(2) Page 21 (Burns and Mohrbacher 2004) – It is stated that it is unclear how thermal and fast neutrons were reported using NTA film with open window (OW) and cadmium (Cd) filters. Has any information been found that indicates that thermal neutrons were

recorded in the dose records? If so, how were they measured, and what method was used for calibration?

Limitations of NTA to measure thermal neutrons were well known, but portable radiation instrumentation could be readily used, and certainly activation of cadmium with subsequent photon emission was a common dosimetry practice. The graphite reactor (experimental ports with appropriate filters) may have been used for calibration. Since it was a research tool, they had well-characterized beams. Thermal neutron dose may not have been reported on the Kardex cards (which may be what prompted the statement in the TBD to begin with). There are measurements to differentiate fast and thermal neutron components of graphite reactor beams and determinations of how the film badge responded to these. They had a tolerance limit for thermal neutrons even though they couldn't measure them.

(3) Page 24 (Burns and Mohrbacher 2004) – It states in the last paragraph that the conditions concerning neutron exposures are likely unchanged over time. This is a broad statement, especially in a research environment. What investigation and documentation supports this concept?

The TBD states "Conditions at reactor, accelerator, and calibration facilities are not likely to have changed significantly over time, and operations at the Radiochemical Engineering Development Center (REDC) have remained consistent over its history." This statement is not as broad as this question suggests. The facilities addressed are static in that they do not undergo major changes in design or fuel. The data given in the TBD, which address variability in workplace fields within these facilities, should therefore be reasonable relative to their uncertainties.

(4) Page 64 (Burns and Mohrbacher 2004) – According to the Occupational External Dose TBD (Burns and Mohrbacher 2004), neutron track Type A (NTA) film and thermoluminescent dosimeters (TLDs) were only processed if the health physicist (HP} requested it, or if it was anticipated that the worker was exposed to neutrons. This seems to be somewhat circular reasoning, in that neutron dose was recorded only if it was known that neutrons were there. This policy could lead to missed neutron dose, especially in the early years before some radiation hazards were identified. Therefore, during DR, the worker could be assigned a missed dose based on limit of detection (LOD), instead of more realistic radiation worker's doses. How will this shortcoming be addressed during neutron DR?

The monitoring records of workers routinely exposed to neutrons would reflect this routine exposure. Additionally, neutron dose is assigned using neutron:photon ratios when it is apparent from the information provided that the employee may have been exposed to neutron radiation.

(5) Page 64 (Burns and Mohrbacher 2004) – NTA film track conversion factors are given as the number of tracks/cm^2/mrem. Should this be in units of the number of tracks/**mm**^{2}-mrem?

No. At 950× magnification, one field was 2 ×10^{-4} cm^2.

(6) Page 65 (Burns and Mohrbacher 2004) – It states that as of 1969, ORNL began doubling the neutron dose values to obtain the recorded dose for unknown spectra. However, as stated elsewhere in the Occupational External Dose TBD (Burns and Mohrbacher 2004), some facilities had the total neutron spectra below the NTA film threshold. Doubling a zero recorded neutron dose (or only a small fraction of the total dose for some facilities) leads to a large missed dose. How will this be handled during DR?

To the best of our knowledge, ORNL never assigned missed dose. The dose reconstructors typically assign dose using the approach in the TBD, using a neutron:gamma ratio.

(7) Page 70 (Burns and Mohrbacher 2004) – It states that the dose reconstructor should use n-p values for neutron DR, unless it is known that the NTA film results were correct. Does this mean that all the discussions in the TBD (Burns and Mohrbacher 2004) concerning NTA film doses will not be used for the most part, but that the n-p method will be used for the majority of the neutron DRs?

Correct. Neutron dose is assigned using a neutron:gamma ratio, which is the approach recommended in the TBD.

(8) Page 71 (Burns and Mohrbacher 2004) – It states that the dose reconstructor should use the n-p dose ratios to estimate missed or ***unmonitored*** neutron doses before 1975. Is this the method proposed by the TBD (Burns and Mohrbacher 2004) for neutron DR that is to be used for unbadged workers who should have been monitored? How will the photon dose be assigned (LOD when photon values cannot be used for unmonitored workers because LOD only applies to workers wearing dosimeters)? Will additional technical information bulletins (OTIBs) be issued to cover neutron doses for unbadged workers?

The TBD is referring to assigning dose for neutron workers. Unbadged workers should not have received any appreciable neutron dose.

(9) Page 69 (Burns and Mohrbacher 2004) – TBD-6 recommends that the DR double the recorded neutron dose from 1950-***present*** (2004) to account for different quality factors. Shouldn't this only apply to NTA film and not TLDs?

No. The TLD results still reflect NCRP 38 quality factors.

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ATTACHMENT 4: SUMMARY OF CONFERENCE CALLS ON SC&A QUESTIONS PROVIDED TO NIOSH

Introduction

SC&A submitted written questions to NIOSH pertaining to the Oak Ridge National Laboratory Site Profile on August 1, 2006. NIOSH/ORAU provided written responses to these questions on August 25, 2006, in preparation for a conference call with SC&A. The questions and responses are provided in Attachment 3. Information provided by NIOSH/ORAU gives SC&A a more in-depth knowledge of the rationale for assumptions made within the TBD and the source documents that provide the basis for the TBD. The summaries below are not verbatim discussion, but include information supplemental to the written responses provided by NIOSH/ORAU. They are arranged by general topics, since there was overlap in discussions conducted during the conference calls. The information provided by NIOSH/ORAU is listed under each topic. SC&A has provided comments towards the end of the summary. Action items resulting from discussions in the conference call are listed at the bottom of each summary.

Participants

NIOSH:	John J. Johnson
ORAU:	Elyse Thomas, Robert Burns, Kenny Fleming, Liz Brackett Matt Smith, Mark Fishburn, Steve Cummings
SC&A:	Kathy Robertson-DeMers, Dr. Abe Zeitoun, Dr. Bob Bistline, Ron Buchanan, Dr. Harry Pettengill, Tom Bell

ORNL Site Description TBD

There was a wide range of particle sizes at ORNL. For particulate emissions from stacks, if they were larger particles, they would settle out on fallout trays. Smaller particulates would be captured by air monitors and included as a part of the data from these units. The height of the units is thought to be 6 feet above the ground level. The same air monitors were in place from 1947 to the early 1980s. Ambient external dose for noble gases was measured initially with the use of ionization chambers (e.g., X-chambers). Inhalation of the particulates is addressed through the environmental data. The environmental dose assessment would be used for some who were not monitored.

Discussions with the current Radiological Control Officer for the Life Sciences Division indicated that there had been no ruptured sources at the ORNL facilities at the Y-12 Plant. Sealed sources were used for animal irradiation, and did not pose an internal hazard. A form was filled out with the use of each source. The focus on sources in this particular area of the TBD was with the Biology Division.

We have tried to pick up information about ruptured sources during the worker interviews and the CATI interviews, but have not had any reports of this happening. The Radiation Area supervisor was contacted and provided NIOSH/ORAU with a list of sources handled in the Life Sciences Division. From the information that has been gained, there appear to have never been

any ruptured sources. NIOSH/ORAU relies primarily on the CATIs and the information obtained from Worker Outreach meetings. They do not generally try to directly contact specific workers, but did contact many individuals within the Radiological Control Operation to obtain additional information.

There are many dates of specific operations and processes that were not included within the ORNL Site Profile. Due to the nature of research that took place at the site, individual log books were maintained by radiation protection staff. These log books, located in storage, denote daily and shift-wise tasks that took place within radiological areas. Where MDA data is missing, the dose reconstructor is provided with claimant-favorable assumptions (e.g., energy ranges, time spent in radiological areas, etc.) to reconstruct dose. For monitored workers, bioassay data are used to assess individual exposures. For unmonitored workers or workers that have gaps in their data, co-worker data are used.

SC&A Conference Call Comments

SC&A is concerned not only about the possibility of inhalation for unmonitored workers, but also for monitored workers. Some consideration should be given to the particle size used to assess these releases. At other sites, particle deposition on the skin has also resulted in some significant doses to personnel. These items deserve further consideration.

The presence of so many processes and operations at ORNL, which introduce numerous radionuclides, is of concern. The Site Description TBD (Fleming 2006b) lists radionuclides and processes that have not been considered in the Internal Dose TBD (Bollenbacher et al. 2006). Table 5A-2 (page 39) shows several time periods where MDA data is missing. It is unclear how dose assignments will be handled for these time periods, or if there was a potential for exposure.

Action Items for NIOSH/ORAU

None.

Action Items for SC&A

(1) Provide a list of action items from the conference call.
(2) Provide a summary of the conference call discussion.

Occupational Medical Dose (ORAUT-TKBS-0012-3)

There is no attempt to subtract any other non-occupational x-ray exposures from the dose of record. NIOSH/ORAU generally do not have enough data to ascertain whether individuals wore dosimeters during x-ray procedures unless the CATI alerts us to this possibility. Correspondence from an area physician indicated a concern regarding some workers being allowed to stand inside the x-ray room when other individuals were receiving chest x-rays. This was done because there were no changing room facilities outside the examination rooms. To resolve the concern, ORNL placed thermoluminescent dosimeters in locations within the x-ray room for a month where workers may have spent time during x-ray procedures to document low exposures. The study

indicated that potential exposures from scattered radiation would not have exceeded 0.08 mrad per chest x-ray examination.

X-ray exams that were required as a "condition of employment" are included in dose assessments. NIOSH/ORAU agrees that screening exams done during employment does constitute an occupational medical exposure. This is inclusive of asymptomatic as well as symptomatic people involved in medical screening.

Medical files (including records of x-ray examinations) are available dating back to the beginning of site operations for ORNL employees, and are stored in the ORNL Medical Records vault. It appears that records from medical examinations conducted at the Oak Ridge Hospital were transferred to the ORNL vault, although there is some uncertainty as to whether all photofluorography (PFG) films completed at the hospital were transferred. The medical records that were reviewed indicated dates that x-ray examinations were conducted. The Internal Dose TBD directs the dose reconstructor to assume all pre-employment chest x-ray examinations were PFGs, and to assume that all other routine or re-takes used 14" x 17" films.

ORAU, with the support of ORNL medical staff, have reviewed a portion of the large set of x-ray records (including films) at the ORNL records vault. The review of a subset of PFG film records indicated they were concentrated around the 1943–1944 timeframe. An individual, from the reviewed set of records, was found to have had two PFGs about a year apart. A discussion with the individual that began working at ORNL as the Radiology (x-ray) Technician in 1947 indicated that chest PFGs were all conducted at Oak Ridge Hospital, and would have been conducted prior to the ORNL x-ray facilities commencing operations (October 1947). PFGs were not observed in any individual medical jackets, but were stored on six shelves with other PFGs that were in the vault. Though no PFG records after 1944 were observed in the vault, it is possible that some may exist, but not very probable. There were several hundred PFGs located on the shelves, and approximately 100 were observed during the site visit.

In the mid-1950s, Dr. K.Z. Morgan instituted a study looking at x-ray exposures from both ORNL Medical and area radiology clinics/hospitals. The results of the study are documented in two peer-reviewed papers written by Drs. Lincoln and Gupton. NIOSH agrees that the purpose of the study was to assess, and possibly determine a mechanism to reduce, gonad exposures from x-ray exams that individuals had at ORNL and offsite.

The filtration used in the Picker Model R-2 unit installed in October 1947 was documented in each of the papers referred to in the preceding paragraph to be 1.0 mm Al total filtration for estimation of entrance skin exposure (ESE). A value of 0.04 mm Al inherent filtration was provided by the Radiology Technician, but assumed to be in error, and a half value layer of 1.5 mm Al was actually used to estimate ESEs. Conversations with Ron Kathren and others indicated that 0.04 mm Al filtration would not have taken into account all the shielding that would have been present in the x-ray tube and housing. As a result, alternate filtration values were used to estimate ESEs. The Radiology Technician pointed out aluminum wedges in a box during a site visit as being used to harden the beam for lumbar spine exams.

Discussions with a Radiology Technician at ORNL from 1947 indicated that the beam was well collimated. There was also a 20-cm cone collimator documented in the referenced papers as being used at least from the mid-1950s.

ORNL provided NIOSH/ORAU with a page of text that identified the equipment that is and was used at ORNL and the operating characteristics. The text provided by ORNL was not in a consistent format and, therefore, the information was extracted from the text and re-organized in Table 3-2. Operating parameters, and the 0.04 mm filtration, were cited in an early handwritten survey conducted to support the study referred to above. The record of the survey is on the NIOSH/ORAU site research database. However, after reviewing and comparing the operating parameters and instruments in use at the time, the 0.04 mm filtration value and exposure time for the Westinghouse Riviera unit were changed. The assumed half value layer was discussed in a previous paragraph. The exposure time was increased by a factor of 10, because the provided exposure appeared low. This assumption is favorable to the claimant. Other than those two items, NIOSH/ORAU relied entirely on information supplied by the ORNL medical staff.

Based upon the reviews of folders made during the visits to the site, NIOSH/ORAU believe the medical files exist for all individuals that have been and still are employed at ORNL (except those that may have been transferred to other sites within the Oak Ridge Operations). These medical files contain color-coded sheets that indicate the date and type of x-ray examination conducted. This available and provided information can be used by dose reconstructors to reconstruct exposure that are favorable to claimants. NIOSH/ORAU believe the medical files contain all necessary information on medical x-ray exposures needed to estimate energy employee dose. This includes the Radiology report for particular x-rays.

There has been research into the possibility of workers lining up inside the x-ray room when chest PFG screenings were being conducted. It is not known what the conditions were in the Oak Ridge Hospital, or what was done at the hospital to ensure that people stepped out of the primary beam area in the x-ray room. In addition to other assumptions that ensure dose reconstructions are conducted that are favorable to claimants, 30% uncertainty is added to the occupational medical x-ray dose. NIOSH/ORAU is conservative on the estimation of ESE, and is confident that dose reconstructions are favorable to claimants. The exposure to individuals standing in the room would primarily be from scatter. This dose would not be significant.

SC&A Conference Call Comments

The responses provided to our questions were fairly straightforward. There are a few items that require further clarification.

There was a period of time (prior to October 3, 1947) when pre-placement chest PFG examinations were conducted at the Oak Ridge Hospital. The TBD states that screening was done at the Oak Ridge Hospital, and that “no PFGs exams of the chest were performed at the ORNL site during physical examinations;” however, PFG films and related records were transferred to ORNL Medical. It appears that at a later date, the PFG films were transferred to ORNL. Use of PFGs for tuberculosis screening was a general application used up to the late 1950s. There should be some level of

investigation into whether ORNL workers continued to be sent to the Oak Ridge Hospital (or any other medical facility) for PFGs after 1947, including for tuberculosis screening. A call was made to Tim Vinson at Methodist Hospital in 2003 to inquire about the type of PFG equipment used in the mid-1940s, and whether PFG films may still be available at the hospital. He thought this was not likely. SC&A believes NIOSH should investigate this further beyond the interview conducted.

NIOSH/ORAU relied on responses from one medical staff person at ORNL, and a review of those responses by the Medical Director, on the frequency of PA chest, LAT chest, and lumbar spine films. Further review of documentation and interviews with former medical directors who actually set policy is encouraged.

In a letter from Dr. T.A. Lincoln to Dr. E. G. Ammermann of the University of Tennessee Memorial Hospital, Dr. Lincoln of ORNL stated the following:

> *Seaton Garrett told me about his recent conversation with you regarding x-ray exposures in the Health Division of the Oak Ridge National Laboratory. He indicated that you were quite critical of our practice of allowing other patients to be in the room at the same time a patient gets his periodic chest x-ray.*
>
> *I want to reassure you that we, too, are concerned about any radiation exposure our employees get.* (Lincoln 1970)

Dr. Lincoln agrees later in his letter that patients should not be in the examining room when another patient is getting an x-ray; however, in order to accomplish the number of exams required, a common practice allowed other workers in the exam room at the same time. This clearly indicates that individuals were allowed in the room while others were receiving x-rays. ORAU, in their response to SC&A questions on August 25, 2006, indicated that the extra exposure to individuals waiting in the x-ray room is likely not greater than the 1% extra dose estimated by Lincoln. We agree that the total dose from this type of scatter exposure is not likely to be significant. It was estimated by Dr. Lincoln that the "exposure was probably less than 1 mrad." (Lincoln 1970). This practice, if it occurred frequently, and how it adds to the occupational medical dose should be considered.

The use of a 1 mm Al filtration is questionable on the Picker Model R-2. This may not be accurate.

The Occupational Medical Dose TBD (Fleming 2004a, pg. 7) indicated the use of the following assumption.

> *Given the disparity between this value and what is typical, a beam quality with an HVL of 1.5 mm Al was assumed for the assessment of worker exposures from this unit. The total filtration given for this device was found documented (Lincoln and Gupton 1958a and 1958b) as 1 mm Al and was used to estimate the entrance skin exposure2 (ESE) values for lumbar spine X-ray examinations for the instrument used between 1947 to 1963. The documented skin exposure in these same reports*

was low (21 mrad) for the PA chest X-ray examination as compared to skin exposures from other chest X rays given during that timeframe. The skin exposure for that timeframe was estimated using operating parameters.

Although the TBD appears conservative, the filtration is likely greater than this and probably on the order of 2.5 to 2.75 mm Al.

Even though the TBD suggests collimation was always used at ORNL, there is no verifiable evidence to suggest the 20-cm cones were effective. ORAU derived organ doses based on an assumption of a poorly collimated beam (Fleming 2006a, pg. 10). Furthermore, efforts should be made to verify the size of x-ray unit cones and when they were used.

Action Items for NIOSH/ORAU

None.

Action Items for SC&A

Provide NIOSH/ORAU with a copy of Lincoln, T.A., 1970, Correspondence between T.A. Lincoln and E. G. Ammermann dated September 15, 1970, no subject, Oak Ridge National Laboratory, Oak Ridge, Tennessee.
(Provided via fax on September 6, 2006)

Occupational Environmental Dose (ORAUT-TKBS-0012-4)

The Environmental Dose TBD focuses on unmonitored workers. Monitored workers would not be within the scope of this TBD. The dose reconstructor relies on ORAUT-PROC-0060, *Occupational Onsite Ambient Dose Reconstruction for DOE Sites* (Winslow 2006a) and ORAUT-PROC-0061, *Occupational X-ray Dose Reconstruction for DOE Sites* (Winslow 2006b) for assignment of environmental and medical dose, respectively. These procedures describe how to address dose from episodic releases.

In the absence of data from the site, NIOSH/ORAU makes use of studies previously completed by other groups, such as the Oak Ridge Dose Reconstruction project. The TBD assumes conservative dispersion coefficients. Particular radionuclides yielding the highest organ dose are assumed for the gross alpha counts prior to the 1950s.

The environmental dose for ORNL individuals located at the Y-12 Plant is based on the higher of the doses between any facilities in Oak Ridge where an individual worked. Employment determinations are made from information provided in NOCTS. If individuals worked at all three sites, the values for K-25 also would be considered.

NIOSH/ORAU feels that dose from resuspended contaminated soil would be captured in the air monitoring data.

SC&A Conference Call Comments

The Environmental Dose TBD overall is well done.

There is a concern that episodic releases (accidents) have not been considered where exposure may be acute rather than chronic. The annual average value may not provide a bounding value for accident scenarios. Some of the releases at ORNL were between 2 and 24 hours. These accidents are mentioned in the Site Description TBD, but not in the Environmental Dose TBD. In these cases, there is a lot of uncertainty about dose to unmonitored workers from outside the normal facilities operations where the worker might have received dose.

The TBD has not taken into consideration any environmental dose other than airborne releases. Certain exposures to radioactive waste may have taken place. There are waste disposition areas, such as the north and south ponds, which may add to exposures. Resuspension and ingestion of radioactive contaminants ought to be considered when dose is reconstructed.

ORNL was involved with a large number of radionuclides, which could have caused exposure during accidents and routine releases. When there is a release from a reactor, there is a whole array of chemicals and radioisotopes released. These radionuclides should be considered in the environmental dose analysis in order to ensure a bounding estimate.

Action Items for NIOSH/ORAU

NIOSH/ORAU will review the differences between the radionuclides in the Site Description and what is apparent from air monitoring data.

Action Items for SC&A

None.

Occupational Internal Dose (ORAUT-TKBS-0012-5)

When dealing with unmonitored workers, NIOSH/ORAU uses co-worker data, if the workers location was unknown and they may have been exposed. If they were known to work in an area with potential exposure, but were not monitored, a co-worker dose is also used.

Table 5-3 of the Internal Dose TBD was obtained directly from ORNL documents, including the footnotes. The reference to consulting the Internal Dose Group was guidance for ORNL personnel, rather than for NIOSH/ORAU personnel. Internal dose estimates are based on guidance provided in ORAUT-OTIB-0018 (Brackett and Bihl 2005) and ORAUT-OTIB-0019 (Brackett 2004). Table 5-3 includes only the most abundant radionuclides.

NIOSH/ORAU is not aware of the use of tritides at ORNL. Building 7025 at the east end of the site was involved in tritium work (i.e., target fabrication), but tritides were not involved. The existence of tritides at ORNL has not been investigated.

NIOSH/ORAU is currently using a revised IMBA program specifically designed for use in the compensation program. The IMBA program has no information related to solubilities. IMBA (ORAU) has some default selections for uranium enrichment; however, the dose reconstrctor assumes 100% U-234, which has the largest dose coefficients. This gives all workers exposed to uranium the benefit of the doubt. There is no default solubility class for uranium or other radionuclides. All cases are done so that the most claimant-favorable solubility class is assumed.

Background uranium in bioassay samples is not subtracted from the gross measurement. All uranium is assumed to be from occupational exposure, which is claimant favorable.

Radon exposure would be included by the dose reconstructor where exposure to radon was indicated. Currently, radon dose is not being looked into at ORNL. The assessment of radon dose would apply only to lung cancers, and for the early period, claimants with lung cancer are being compensated. Therefore, there is probably no impact for not assessing radon dose.

It would be helpful to have a discussion about when to assume Am-241 exposure and when to assume Cm-244 exposure. Some information on the timeframe and possible location for curium-244 in the TBD would be helpful. The use of Am-241 versus Cm-244 is based on the purity and time period it was handled.

The dose reconstructor will determine if the individual has a potential for exposure and apply the co-worker dose or the environmental dose. Chronic intakes are assigned to individuals with bioassay data.

There is not much difference between inhalation and ingestion dose. Inhalation is assumed as the mode of intake, which is a conservative assumption. In the case of soluble compounds, there is little difference between the dose from inhalation and ingestion. When using air monitoring data, there is a fraction added for ingestion.

The Super Type S OTIB will outline how to assess doses from intakes of this type. This is a general document; however, some site-specific documentation will have to be given. Any site working with PuO2 or Pu will need to be evaluated for the possibility of exposure to high-fired oxides. The model has been developed; however, the team is in the process of identifying when it will be applied.

The MDA values for ruthenium were not questioned. It is somewhat strange that the MDA for ruthenium increases rather than decreases over time.

There is no plan to revise the ORNL TBDs further at the current time.

SC&A Conference Call Comments

There is a general concern over the lack of consideration for exposure to a number of radionuclides. Dose from the ingrowth of Am-241 has not been considered. Tritides, which are not picked up by traditional monitoring methods, have not been investigated. The defaulting to Am-241 as the transplutonium radionuclide of choice, when Cm-244 was handled at the site,

potentially leads to missed dose. In a June 1944 memo, it was determined that radon levels were as high as 6,700 pCi/L, which constituted a significant dose hazard. With the handling of radium in the early years, radon exposure should be evaluated for those workers. There may be processes at ORNL involving exposure to high-fired plutonium oxide, such as with the fuel cycle, microspheres and gels, and catalytic carbon, where this will be involved.

There is no mention in the TBD regarding dose from ingestion. With some of the highly soluble isotopes used at ORNL, there is a possibility of workers receiving ingestion dose. Ingestion would be particularly relevant to the assignment of dose using air-monitoring data in the 1940s.

Some of the minimum detectable activities (MDAs) on page 16 and Table 5-9 (page 39) in Appendix 5A have wide variabilities. For example, Ru-106 has an MDA in 1951 of 0.03 dpm/24 hour sample. It is counterintuitive to believe that as equipment and methods improved, the MDA would increase. By 1960, the MDA jumps to 61.85 dpm/24-hours.

Inconsistencies exist between the ORNL and LANL TBDs with regard to recommendations for the default solubility class for uranium.

Action Items for NIOSH/ORAU

(1) NIOSH/ORAU will investigate the potential for occupational exposure to radon at ORNL.

(2) NIOSH/ORAU will evaluate whether high-fired oxides and tritides are potential sources of exposure at ORNL.

(3) The inclusion of dose from Am-241, as an impurity in plutonium, will be included in subsequent revisions of the TBD.

Action Items for SC&A

None.

Occupation External Dose (ORAUT-TBKS-0012-6)

Workers entering restricted areas more than 3 days per week were assigned routine beta-gamma monitors. Those entering the areas for less than 3 days a week were not assigned a routine dosimeter, but they were provided with a temporary dosimeter. PICs were assigned to these employees, like any other employee.

On the handwritten records, the blank indicates that an individual was not monitored. A zero indicates that the dose was less than the minimum detectable dose. Both types of records are provided in claimant files. Between the manual cards and the computer printouts, the dose reconstructor will use the form that provides the most information. This is usually the hardcopy record.

The skin dose will be assigned based on ORAUT-OTIB-0017 (Merwin 2005), which addresses assigning dose to the skin, breast, and testes. There is skin dose data prior to 1961, which can be used to assign dose. No reliable data during the period of time when PICs were used is available. A co-worker dose can be used to assign dose where necessary.

There was also enough data (experimental in nature) in the early period of 1943–1944 to develop a co-worker model for 1943–1944. This data was likely film badge data. The co-worker model was developed from CEDR data which was obtained from ORNL. ORAUT-OTIB-0021 (Merwin 2004) provides the details of the model. Unmonitored workers would receive this appropriate co-worker dose.

The primary basis for assigning neutron dose in the NTA era and before is the application of a neutron-to-photon (n-p) ratio. It is felt that the later spectral is representative of conditions in the earlier years. NTA results are only used when the NTA dose exceeds that calculated with the n-p ratio. In the mid- to late-1940s, operations at the site primarily involved the Graphite Reactor. The neutrons encountered were mostly thermal neutrons. There is no reason to suspect that changes would occur in the n/p for the Graphite Reactor.

The fraction of dose equivalent above the energy cutoff for NTA film will not be used for dose reconstruction.

Missed neutron dose is applied to those that are monitored during their career. If the worker indicates through the CATI that they were exposed to neutrons, the n/p ratio is assigned to the co-worker doses. The n-p ratio will be used to determine doses for those individuals who received neutron exposure. In OTIB-0021, Section 4, paragraph 4 (Merwin 2004), it does discuss neutron dose and it recommends use of co-worker data for unmonitored workers. Applying n-p ratios in cases where neutron exposure is expected is not covered in OTIB-0021. The TBD predates the OTIB.

The correction factor of 2 should be applied to NTA film, as well as TLDs. The correction factor converts the site-derived dose based on NCRP 38 (NCRP 1971) to a dose based on ICRP 60 (ICRP 1990). This factor has been applied at almost all DOE sites.

SC&A Conference Call Comments

The TBD requires some clarification on how external monitoring was determined, and how comprehensive this monitoring was. This is especially true of the early years. Clarification is also needed on whether PICs were used in lieu of film badges, especially in the 1940s.

There needs to be further verification that the n-p ratios in the 1980s are representative of those in the 1940s. The equivalency of the facilities has not been demonstrated.

Action Items for NIOSH/ORAU

(1) NIOSH/ORAU will investigate whether the comment under the table in Attachment 6C is appropriate.

Action Items for SC&A

None.

References

Brackett, E. M., 2004, *Technical Information Bulletin – Analysis of Coworker Bioassay Data for Internal Dose Assignment*, ORAUT-OTIB-0019, Rev. 00, Oak Ridge Associated Universities, Oak Ridge, Tennessee, December 29, 2004.

Brackett, E.M., and Bihl, D.E., 2005, *Internal Dose Overestimates for Facilities with Air Sampling Programs*, ORAUT-OTIB-0018, Revision 01, Oak Ridge Associated Universities, Oak Ridge, Tennessee, August 9, 2005.

ATTACHMENT 5: CONSISTENCY AMONG SITE PROFILES

The default site profile assumptions and methodologies for Oak Ridge Associated Universities (ONRL) are summarized below and were compared to those of other site profiles reviewed to date or in current review. Site profiles completed to date by the SC&A team include Bethlehem Steel, Mallinckrodt Chemical Works (MCW), Iowa Army Ammunition Plant (IAAP), Hanford, the Savannah River Site (SRS), the Y-12 National Security Complex (Y-12 Plant), Idaho National Engineering and Environmental Laboratory (INEEL), the Nevada Test Site (NTS), the Rocky Flats Plant (RFP), the Mound Plant (Mound), Los Alamos National Laboratory (LANL), the Linde Ceramics Plant (Linde), and the Pinellas Plant. Additional site profiles in the process of review are the Fernald Environmental Management Project (Fernald) and the Paducah Gaseous Diffusion Plant (Paducah). ORNL had multiple missions that overlap with a number of other sites in the DOE complex, such as weapons research, the heat source program, reactor research, assembly and disassembly operations, and tritium operations, to name a few.

To ascertain the differences in assumptions between what assumptions are used for the ORNL Site Profile versus other site profiles, the assumptions from each ORNL TBD must first be understood. The core assumptions for each TBD have been outlined below.

Dose Reconstruction Assumptions for Occupational Medical Exposure

Diagnostic x-ray procedures required as a "condition of employment" included preplacement, routine annual, and termination exams. There was a limited amount of site-specific data related to x-ray equipment and techniques in the TBD. Table 3-3 in the Occupational Medical Dose TBD (Fleming 2006a, pg. 18) summarized the type of x-ray equipment used at ORNL from 1947 to 2002, and provided information on location, techniques, x-ray conditions, type of people receiving examinations, and the changing frequency of chest x-rays, depending on age, after 1990. Information provided in ORAUT-TKBS-0012-3, Table 3-2 (Fleming 2006a, pg. 17) indicates that x-ray frequency through the operating period ranged from annually to every 3 years and after 1990, from annually to every 2 years, depending upon age. Table 3-3 (Fleming 2006a, pg. 18) provides ORNL-provided operating parameters and assumed operating parameters for the purposes of dose reconstruction. Claimant-specific information is provided to NIOSH by ORNL, and is used to supplement the frequencies listed in ORAUT-TKBS-0012-3, Table 3-2 (Fleming 2006a, pg. 17). The basis for the ORNL Occupational Medical Dose TBD (Fleming 2006a) is the *External Dose Reconstruction Implementation Guideline* (NIOSH 2002) and ORAUT-OTIB-0006, *Technical Information Bulletin: Dose Reconstruction from Occupationally Related Diagnostic X-ray Procedures*, Revision 2 (Kathren 2003b). In the absence of site-specific data, the ORNL Site Profile relied on values provided in this document for occupational medical exposure.

The default values for occupational medical dose are the same as those used in other site profiles, as noted on the following pages of the Occupational Medical Dose TBD (Fleming 2006a).

- Routine x-ray frequency through the operating period ranged from annually to every 3 years. Claimant-specific information was used to supplement the frequencies listed in ORAUT-TKBS-0012-3, Table 3-2 (pg. 17).

- Exam included posterior-anterior (PA) chest x-rays, lateral chest x-rays, anterior-posterior (AP) lumbar spine x-rays, lateral lumbar spine x-rays, and stereoscopic photofluorography (PFG) with two views (pg. 20).

- All employees were assumed to have received a preplacement stereo exam if employed between 1943 and October 3, 1947. Lumbar spine exams were assumed for crafts personnel from April 6, 1950, through September 23, 1953 (pg. 18).

- PFG dose values provided in Table 3-4 assume two exposures. This value should be divided by two if the record indicates only a single view (pg. 11).

- The PA chest and AP Lumbar spine thicknesses were assumed to be 26 cm. Thickness used for lateral lumbar spine and lateral chest x-rays was 34 cm. A 5-cm distance was assumed between the film and the individual's body. Adjustments were made for larger workers. For example, lateral chest x-rays were estimated for large workers by multiplying the PA Entrance Skin Exposure (ESE) by a factor of 2.0 (pp. 9–10).

- Dose conversion factors (DCFs) prior to 1963 were based on poor collimation and thus were obtained from ORAUT-OTIB-0006, Table 4.0-1 (ORAU 2003b). After 1963, the units were considered to be well collimated, and DCFs outlined in International Commission on Radiation Protection (ICRP) Publication 34 (ICRP 1982) were used (pp. 15, 20–21).

- Source-to-image distance for chest, PFG chest, and lumbar spine exams were assumed to be 183 cm, 122 cm, and 99 cm, respectively (pg. 18).

- The ESE for the AP lumbar spine x-ray presents both the AP and spot AP exposures.

- The ESE for the lateral lumbar spine x-ray presents both the lateral and spot lateral exposures.

- Single-phase units were assumed until 1990 (pg. 10).

- Values are dimensionless backscatter factors from Table B.8 of NCRP 102 (NCRP 1989). Values for half value layers = 2.5 and 3.5 were obtained via linear interpolation. (pg. 22, footnote to Table 3.5).

- Skin dose calculations include backscatter factors from Table B.8 in NCRP 102 (NCRP 1989). Values for half value layers of 2.5 and 3.5 were determined by linear interpolation (pp. 21 and 23).

- For organs included in IREP that are not specifically identified in ICRP 34, the DCFs for analogue organs that were anatomically the closest to the organ in question were used. (pp. 14 and 34).

- Table 3-2 does show techniques and x-ray conditions for several different types of x-ray equipment used from 1947 to 2002 (pg. 26).

- DCFs for lumbar spine examinations are not given in ICRP 34; therefore, values for the upper gastrointestinal tract exams (AP and LAT) were used (Table 3-5, pp. 20–21).

- Uncertainty for x-ray procedures is 30% (pg. 11).

Overall, the default values assigned for determining medical exposure are relatively consistent among site profiles. The site profile applies OTIB-0006, Revision 2, dated December 29, 2003, although a subsequent version was released on December 21, 2005. This version predates the issuance of Rev. 01 PC-1 of the TBD, dated July 21, 2006. The later version of OTIB-0006 (Kathren and Shockley 2005) provides guidance on the assignment of dose from lumbar spin exams, which were given at ORNL. This should be corrected in subsequent revisions of the TBDs. Other deviations from the standard assumptions are based on site-specific information.

Dose Reconstruction Assumptions for Occupational Environmental Exposure

ORAUT-TKBS-0012-4 (Burns 2004b) describes the default assumptions for occupational environmental dose at ORNL. Occupational environmental dose included internal exposures from onsite atmospheric radionuclide concentrations, and external exposure from submersion and ambient radiation. Values derived for occupational environmental dose were based on environmental measurements (i.e., air monitoring data) and emission rates. Attachment 4B (pg. 40) provides a summary of the annual average airborne concentration data and the associated intakes for an individual assumed to be exposed to the average concentration for 2,000 hours breathing at a rate of 1.2 m^3 per hour.

Other assumptions made with respect to environmental dose from the Occupational Environmental Dose TBD (Burns 2004b) include the following:

- “The three principal contributors to inhalation dose individuals could have been exposed to in the outdoor air on the ORNL site were I -131, particulate mixed fission products (MFPs), and tritium. Lack of available monitoring data, for I-131 in particular, required that bounding values of dispersion coefficients coupled with available source term estimations be used to establish the needed onsite airborne concentration and intake data for certain periods” (Burns 2004b, pg. 27).

- All airborne concentration data are provided in terms of annual averages (pg. 27).

- Site-wide annual average exposure rate values include natural background and contributions from fallout (pg. 27).

- Annual average site-wide exposure rates for 1947 were assigned to 1944 through 1946. The average exposure rate for 1970 was assigned to years 1971 through 1975. The 1984 data was assumed for 1985–2003, and 1982 (pg. 27).

- Intakes associated with annual average airborne concentration data were based on 2,000 hours of exposure with a breathing rate of 1.2 m^3/hour (pg. 28).

- Values developed by ORNL were used to estimate ground-level concentrations resulting from local, low-elevation releases (pg. 28).

- From 1944 through 1965, airborne I-131 concentrations on the ORNL site had to be established using information on emission rates and bounding values of dispersion coefficients. Three different dispersion coefficients were used to derive local onsite concentrations of I-131 from the 3020 stack, the 3039 stack, and fugitive emissions (pg. 29).

- The total quantity of I-131 available from the processes was used to determine bounding, ground level concentrations until 1961 (pg. 30).

- A factor of 2 is applied to I-131 release data in 1961 through 1965 to account for sample line losses (pg. 31).

- The average values measured from the charcoal cartridges for the Local Air Monitoring (LAM) stations were used to determine concentrations for 1966–1984. The average annual concentration from 1984 was applied to subsequent years (pg. 31).

- I-131 is considered a soluble or reactive vapor (pg. 31).

- Annual concentration and intake data are provided for MFPs. These values are based on the average reported gross beta measurements from the LAM network. MFP dose is considered negligible; however, if included in the dose reconstruction, the recommended activity should be based on Type S Ru-106 or Ce-144, depending on which yields a higher dose for the organ of interest (pg. 31).

- No monitoring data were available for airborne tritium concentrations; therefore, concentrations were established based on inventory, release data and conservative diffusion coefficients prior to 1984. Tritium is not considered a significant source term before 1967 (pp. 32, 39–40).

- Intake values for tritium include a factor of 1.5 to account for direct skin exposure. The assumed form of tritium is HTO (tritiated water vapor). A geometric standard deviation of three is used (pg. 32).

- A site-wide average was chosen to be the most representative of the unmonitored worker's exposure profile. If the workers dose is identified as coming from a specific source, the values for the specific source or the site wide-average can be chosen (pg. 33).

- A summary of total annual airborne releases of I-131, tritium, Kr-85, and Xe-133 reported by ORNL is included in Attachment 4A. All values are given in total curies discharged to the atmosphere (pg. 39).

Review of site profiles to date indicates that the NIOSH/ORAU team has not come to a consensus on what components should be considered in the environmental dose. Dose from the resuspension of contaminated soil has not been considered in the Occupational Environmental Dose TBD (Burns 2004b). This source of exposure was considered at the Rocky Flats Plant (McDowell-Boyer and Little 2004) and the Savannah River Site (Scalsky 2005). Ambient external exposure from contaminated soil was also not considered. As with many of the site profiles, there is no consideration of potential exposure from liquid effluents at ORNL.

Dose Reconstruction Assumptions for Occupational Internal Exposure

The internal dose TBD, ORAUT-TKBS-0012-5 (Bollenbacher et al. 2006), describes the default assumptions for occupational internal dose at ORNL. The assumptions were derived from historical records relating to the in-vivo, the in-vitro, and the air monitoring programs. As shown in Table 5A-2 on page 39 of the Internal Dose TBD (Bollenbacher et al. 2006), MDAs have been determined for gross alpha, gross beta, and 16 radionuclides found in urinalysis sampling (Am-241, Cm-244, Cs-137, H-3, I-131, Np-237, Pm-147, plutonium, polonium, Pu-241, Ra-226, rare earths, Ru-106, Sr-89 + Sr-90, and gross alpha), and 4 radionuclides found in fecal samples (Am-241, Cm-244, plutonium, and Th-232). Figures 5A-1 through 5A-18 (Bollenbacher et al. 2006, pp. 40–65) show plots of data obtained and calculated for the following radioisotopes: (urine) Am-241, Cu-244, Cs-137, gross alpha, gross beta, H-3, Pm-147, Pu-238, Pu-239, Pu-230, rare earths, Sr-90, U-233, U-238; and (feces) Am-241, gross alpha, Pu-239, Th-232. In the first plot, the MDA values were plotted against the date of their analysis.

Other assumptions related to in-vitro analysis in the Occupational Internal Dose TBD (Bollenbacher et al. 2006) include the following:

- Because of the diverse operations occurring at ORNL, the compilation of a comprehensive list of radionuclides handled by ORNL employees would be difficult to assemble. The radionuclides assumed to produce a measurable dose at this facility include uranium, activation products, fission products, and transuranics (pg. 10).

- Dose reconstructors should choose the radionuclide and tissue(s) of interest using the solubility classes in ICRP Publication 66 (ICRP 1994). (pg. 10).

- Assume inhalation with a particle size of 5-micron Activity Median Aerodynamic Diameter (AMAD) particle size (pg. 10).

- Table 5-2, page 10, provides the assumptions on solubility classifications used by ORNL for re-evaluation of historical bioassay results. The default absorption for uranium is Type S.

- In-vitro monitoring data from an ORNL database were used to estimate MDAs. The MDAs were calculated from analytical records recovered from the database (pg. 12).

- Plutonium-238, Pu-239, and Pu-240 were carried through in the total plutonium analysis. Alpha spectroscopy in 1989 allowed the lab to distinguish between Pu-238 and Pu-239. Plutonium-241 is reported separately, because it is a beta emitter (pg. 15).

- Table 5-9 provided the annual average MDAs (dpm/24-hr sample) for 1947 through 1989, with the blanks indicating no analytical results were found (pg. 16).

- Assume Am-241 for measurements involving trivalent alpha actinides, unless results suggest otherwise (pg. 18).

- The default radionuclide assumed for positive total plutonium measurements is Pu-238 (pg. 18).

- There is no mention of subtracting background radiation from the in-vitro results in the ORNL Internal Dose TBD.

Other assumptions discussed in the ORNL Occupational Internal Doe TBD (Bollenbacher et al. 2006) related to in-vivo counting include:

- Assumed mean body burdens of Cs-137 from fallout in the United States are provided in Table 5-16. ORNL used a value of 20 nCi Cs-137 for consumers of venison (pg. 26).

- Table 5-12 of the ORNL Internal Dose TBD provides the 1965 criteria for whole-body counting. This table does not exclude Cs-137 (pg. 21). ORNL uses a value of 20 nCi Cs-137 in a whole-body count for consumers of venison as the decision level to follow up or conduct a dose assessment (pg. 25).

- The ORNL Internal Dose TBD states, “It is a property of the Poisson distribution that its standard deviation is the square root of its mean value. Therefore, in this analysis, the standard deviation of the total background counts was calculated as the square root of the total background counts” (pg. 37).

- “The default radionuclide to use with measurements involving trivalent alpha actinides would be Am-241” (Bollenbacher et al. 2006, pg. 18).

- Table 5-15 summarized the maximum activity measured by in-vivo monitoring from 1961 to 1966. The list of radionuclides includes Na-24, Sc-48, Cr-51, Co-56, Co-57, Co-58, Fe-59, Co-60, Co-64, Zn-65, Se-75, Sr-90, Zr/Nb-95, Ru/Rh-106, Sb-125, I-131, Cs-137, Eu-155, Hg-203, Ra-226, Pa-233, and enriched uranium (pg. 24).

Assumptions discussed in the ORNL Occupational Internal Dose TBD (Bollenbacher et al. 2006) related to use of air sampling data include the following:

- ORNL maintained early tolerance levels for airborne contamination based on “product” (i.e., Pu-239) concentrations in the air (Cox 1944) (pg. 9).

- Air-monitoring records for 1944 to 1947 can be used for assigning best estimates of dose (pg. 28).

- The basis for estimation of internal dose by air sampling is presented in Internal Dose Overestimates for Facilities with Air Sampling Programs (ORAU 2005) with ORNL-specific modifications. Alpha emitters are limited to uranium and plutonium. The dose is entered into IREP as a constant. Air-monitoring data prior to June 1944 is assumed. Airborne rates would be less than in later periods (pg. 28).

- Exposure to the maximum permissible concentration for 40 hours a week, 50 weeks per year (pg. 67).

- The radionuclide that results in the largest intake is assumed to comprise 100% of the intake. The radionuclides may change from year to year (pg. 67).

- The ORNL Internal Dose TBD did not discuss the establishment of boundary conditions for chronic intakes.

- In the ORNL Internal Dose TBD, Table 5A-2 in Attachment 5A, page 39, provides annual averages for periods of time where bioassay data were available. This table includes MDAs calculated from recovered data for radionuclides. The table shows data for Pu starting in 1946, for 2 or 3 others by 1949, and for 8 radionuclides by 1952. There is no discussion of applying 1951 data to earlier periods.

External Exposure

The ORNL Occupational External Dose TBD ORAUT-TKBS-0012-6 (Burns and Mohrbacher 2004) describes the default assumptions for occupational external dose at ORNL. The dose assignments were based on pocket dosimeter, film badge, and thermoluminescent dosimeter results. Attachment 6A gives the IREP energy groupings for photon exposure by facility (pg. 76). Attachment 6B contains a list of ORNL facilities where workers may have received neutron exposure, their dates of operation, and the appropriate neutron energies (pg. 24). Attachment 6C contains a summary of neutron-to-photon ratios derived from field measurements (pg. 24), and is provided for information purposes primarily. Attachment 6D provides the neutron-to-photon ratios derived from dosimetry records as a function of worker group (pg. 45).

Assumptions related to beta/gamma and neutron exposures include the following (Burns and Mohrbacher 2004):

- The ORNL dosimetry system became DOELAP-approved and Hp(10) doses were recorded. No exposure to organ-dose conversion factors is necessary (pg. 16).

- Claimant-favorable assumptions should be applied for radiation types and energies when converting to organ doses (pg. 22).

- The recommended photon energies are > 250 keV (75%) and 30–250 keV (25%), except at certain accelerator and transuranic facilities where the shallow dose could be treated as 100% <30 keV photon or 100% >15 keV electron. The choice should be made based on job responsibilities (pg. 22).

- Unlike the LANL External Dose TBD, which states that beta and photon energy distributions are determined by area (Widner 2005, pp. 69–70), the ONRL External Dose TBD does not discuss this.

- 100% AP geometry is assumed for all workers (pg. 23).

- In the ORNL External Dose TBD, it states that "…dose reconstructors should apply claimant-favorable assumptions for radiation types and energies when converting deep and shallow beta-gamma dosimeter dose for ORNL workers to organ dose for input to the Interactive RadioEpidemiological Program (IREP)" (pg. 22).

- The ORNL External Dose TBD cites the following reference regarding the use of a factor of 2.5. "The purpose of the term 2.5 (W–P) in the expression for DS above was to represent the beta portion of the total dose, with the factor of 2.5 being a correction for the attenuation by the OW and plastic filters relative to a dose depth of 7 mg/cm^2. The factor of 2.5 was based on the beta spectrum from natural uranium, but different factors could be used if there was evidence of exposure to a different beta energy (Thornton, Davis, and Gupton 1961)."

- The ORNL External Dose TBD photon missed dose values in terms of LODs for deep dose and dosimeter exchange frequencies on ORNL radiation workers are to be done in accordance with Table 6-24 (pg. 69). The use of MDL/2 is not discussed. LODs and exchange frequencies are provided in Table 6-24 (pg. 69) for certain periods.

- Review of claims indicates that B values are the difference between OW and shielded readings; therefore, the results should be interpreted as such (pg. 60).

- Apply an organ dose conversion factor to the deep dose results for the period of 1989 (pg. 67).

- Before 1961, sum the beta and gamma values to obtain the shallow dose (pg. 67).

- Multiply the OW values from 1944 to February 1947 by a factor of 2.2. Multiply the OW results by 0.9 from February 1947 through February 1951. These factors represent adjustment factors to account for calibration differences (pg. 67).

- If any reported neutron dose data are used, the fast neutron value should be multiplied by factor of 4 for 1943–1950 and a factor of 2 for 1950–1968 (pg. 68).

- Missed shallow dose should apply the LOD values for deep dose unless the field consists of primarily low-energy beta. In this case, if Centralized External Dosimetry System (CEDS) TLD were used, the LOD was 14 mrem/quarter (pg. 69).

- Use neutron-to-photon ratios unless the NTA film yields a high dose. These ratios should be applied to both recorded and missed photon dose where neutron dose is anticipated (pg. 70).

- For reactors or other facilities not addressed in Attachments 6C or 6D, evaluate the applicability of the distribution of neutron-to-photon dose ratios derived from the ORNL personnel monitoring records for similar facilities or job duties, the distribution for all facilities, or the distribution yielding the maximum ratios (pg. 71).

- Uncertainty factors for reported ORNL doses are provided based on characterization of dosimeters by site personnel and the DOELAP analysis. The standard error used for beta/gamma film badge doses is estimated to be ± 30%. The error for a neutron dose with a 100 mrem reading is estimated at ± 50%. For dosimeters used after the mid-1970s, the standard errors for a 100 mrem exposure were approximately ±15%.

- In the ORNL External Dose TBD, in footnotes of both Attachment 6C (pg. 79) and Attachment 6D (pg. 80), both dealing with neutron-to-photon ratios at ORNL, states that the geometric mean, minimum, and maximum should be doubled to account for ICRP 60 radiation weighting factors.

- Dose reconstructors should refer to the neutron-to-photon dose ratios in Attachments 6C and 6D to assign missed and unmonitored dose for individuals who received neutron exposures in comparable facilities or job duties (pg. 71).

- In the ORNL Site Description TBD, it is pointed out that neutron exposure potentially occurred at the accelerators, the Building 7735 Dosimetry Applications Research Calibration Laboratory (DOSAR), the ORNL Research Reactor in Building 3042 (ORR), the Tower Shielding Facility (TSF) in the 7700 area, the neutron flight tube facility (3083), the Neutron Users Office and Lab (7962), the Neutron Science Support Center (7970), isotope separations facilities, transuranic facilities, and waste storage and disposal facilities (pg. 77).

- Table 6-23 provides group-weighted NCRP 38 (NCRP 1971) quality factors and correction factors used to convert NCRP values to the appropriate ICRP 60 (ICRP 1990) value. Conversion factors are 2.1 for thermal neutrons, 1.9 for 0.01–2.0 MeV neutrons, and 1.3 for 2.0–14.0 MeV neutrons (pp. 68–69).

- For 1975 to the present, neutron missed dose can be estimated on the basis on LODs and dosimeter exchange frequencies (Burns and Mohrbacher 2004, pg. 71).

- The ORNL External Dose TBD provides the following guidance regarding the assignment of dose by work location: if possible: "….actual personnel neutron and

photon exposures and should be used in favor of the values given in Attachment 6C as practicable. The values in Attachment 6C are derived from characterization of workplace neutron spectra performed in conservatively chosen locations with high neutron dose rates" (pg. 71).

- A co-worker model is available for beta/gamma exposures; however, a method has not been developed for neutrons (Merwin 2004).

The default assumptions for entry of individual dose into IREP are consistent with those used in other TBDs. As with other site profiles, the missed photon dose is determined by dividing the Minimum Dose Limit (MDL) by 2 and multiplying by the number of zeros and unmonitored periods. The missed photon dose is entered into IREP as a lognormal distribution with a geometric standard deviation of 1.52. Dosimeter correction factors are based on site-specific information, which is appropriate.

Inconsistencies within the ORNL Site Profile

The TBD states that it does not address skin exposure, yet it provides shallow dose correction factors. Furthermore, during the SC&A conference call with NIOSH, the dose reconstruction representatives indicated that the shallow dose is assigned using OTIB-0017 (see Attachment 4). This appears to be providing a methodology to assess skin exposure. Clarification on shallow dose calculation is needed in the TBD.

The Site Description TBD identifies radionuclides by facility and includes information on incidents and spills that occurred in the facilities. Some, but not all, of this information is considered in the Environmental Dose TBD and the Internal Dose TBD. In particular, there are radionuclides (e.g., medical isotopes) that have not been included in the dose calculations. These radionuclides should be evaluated to determine their significance to environmental and internal dose.

Inconsistencies between Site Profiles

Some variation occurs between several of the TBDs with respect to the assumed chest thickness. The TBD (Fleming 2006a, Table 3-3, pg. 18) assumes a PA and lateral chest thicknesses of 26 and 34 cm, respectively, at ORNL; AP and lateral LS thicknesses of 26 and 34 cm, respectively; and distance from body to imaging surface of 5. The SRS TBD (Scalsky 2005) assumes 26 cm and 34 cm for PA chest x-rays and lateral chest x-rays, respectively. The Hanford and ORNL TBDs actually recommend adjustment factors for chest thickness. There is no mention of applying a factor of 2.5 to the PA x-rays to estimate the ESE for lateral chest x-rays. This factor has been included in many of the other TBDs and OTIB-0006 (Kathren and Shockley 2005, pg. 20).

The Occupational Medical Dose TBDs for Y-12 (Murray 2003), SRS (Scalsky 2005), and Hanford (Scalsky 2003) base their default exposure geometry on the compensability or non-compensability of the claim. The MCW (Westbrook 2005) and RFP (Furman and Lopes 2004) Occupational Medical Dose TBDs base default exposure geometries on job titles. Both the

ORNL TBD (Fleming 2006a) and the INEEL (Rohrig 2004) Occupational Medical Dose TBDs choose to default to 100% AP exposure. Further evaluation of exposure geometry for photon and neutron exposure should be evaluated for ORNL workers to determine if 100% AP geometry is appropriate for all ORNL workers. The NIOSH/ORAU team should consider development of a consistent default assumption for exposure geometry in all site profiles.

The ORNL Environmental Dose TBD assumes that average annual site-wide values are assigned to unmonitored workers. For LANL and SRS, when the worker location is unknown, the site-wide maximum ambient radiation dose is assigned (Cehn and McDowell-Boyer 2004; Scalsky 2005). The application of multiple receptor points would be consistent with the approach in the Hanford, SRS, and INEEL TBDs. The use of measured air concentration data is consistent with the Y-12 Occupational Environmental Dose TBD (Ijaz and Adler 2004). The ORNL TBD (Burns 2004b) appears to rely on emission and measurement data; however, it does not indicate the model used for calculations. The TBD generally discusses particle size; however, the actual particle size assumptions for assignment of internal dose have not been provided.

The ORNL TBD assumes exposures from I-131, H-3 (starting 1967), Kr-85, Xe-133, and MFPs (optional). Other site profiles have considered radionuclides hat were present at ORNL. The Hanford TBD included plutonium, noble gases, and MFPs (Savignac 2003). The SRS TBD included tritium, noble gases, plutonium, and uranium (Scalsky 2005). The LANL TBD included tritium, noble gases, plutonium, americium, uranium, and thorium (Cehn and McDowell-Boyer 2004). Several of the ORNL workers were stationed at the Y-12 Plant location, indicating these radionuclides may not be applicable. Y-12 Plant handled primarily uranium, with some processing of thorium and U-233 (SC&A 2005). These radionuclides have not been considered in the assignment of dose to workers at the Y-12 facility.

With the LANL Environmental Dose TBD, a screening method was applied to the source term to determine relative dose consequences for different radionuclides. With the similarities in the breadth of radionuclides handled at ORNL and LANL, this screening method or equivalent is considered prudent at ORNL. Overall, SC&A believes that further investigation into environmental source terms is needed.

The ORNL Internal Dose TBD lacks guidance on the activity fractions for plutonium and thorium. For example, SRS assumes a 10-year old, 12% plutonium mixture (Scalsky 2005). Activity fractions for plutonium provide critical information for the assessment of dose from americium as an impurity. Americium doses have been considered in other site profiles. The ORNL TBD is silent about exposures from recycled uranium (RU), although it is considered in the Y-12 TBD (Rich and Chew 2006). The Y-12 site supplied materials to ORNL and had individuals stationed at the Y-12 Plant site. There is no mention of whether special tritium compounds were handled at ORNL, and how intakes from this material are to be treated. Further investigation should be conducted related to ORNL employee exposure to RU and tritides.

There is mention of the presence of the release radon from stacks and storage areas; however, no discussion was included for potential internal dose to radon. It would seem reasonable that radon would be present in the workplace if it were being released to the environment. Radium-226 and ores were also handled at ORNL. Radon was specifically mentioned in the MCW and Fernald

TBDs, where high concentrations of Ra-226 were handled. The ORNL Site Profile fails to consider radon exposure. The impact of radon on dose reconstruction should be evaluated, particularly for the early years.

During the Y-12 Special Exposure Cohort petition review, considerable attention was given to radionuclides generated by the ORNL Isotope Production Group and potential exposures to Y-12 workers from these activities. ORNL employees were stationed at the Y-12 Plant and actively ran these operations. The radionuclides of concern for Y-12 Plant are H-3, Sr-90, Tc-99, Th-228, Th-232, U-232, U-233, U-236, Pu-238, Pu-239, Pu-241, Np-237 Am-241, Co-60, Zr/Nb-95, and Po-208. This is a somewhat different mixture of radionuclides than those considered for missed dose at the ORNL main site. The Internal Dose TBD (Bollenbacher et al. 2006) does not include a discussion on accelerator-produced radionuclides, or medical isotope production and how these are handled in dose reconstruction in terms of missed dose.

There has been no consideration of ingestion dose for ORNL, particularly when air sampling data is used to determine internal dose. The Bethlehem Steel and MCW TBDs included ingestion as a potential route of internal dose. This may be particularly important at LANL in the early years.

The ORNL Internal Dose TBD does not refer the dose reconstructor to the specific guidance provided in OCAS-TIB-002 (OCAS 2003) when the dose records indicate an exposure to organically bound tritium (OBT) and metal tritides (MTs). This referral was made in the LANL Internal Dose TBD (Argall 2004). The Mound Internal Dose TBD (Millard 2004), in Section 5.3.1.1, Metal Tritides, states that a lung clearance class of S should be assumed for all metal tritides other than lithium. The SRS Internal Dose TBD and associated TIBs fail to treat the topic of dose reconstruction from exposure to organically bound tritium and metal tritides. Consideration should be given to identifying those facilities with special tritium compounds and developing a common methodology to assign dose from the compounds.

In general, the Integrated RadioEpidemiology Program (IREP) input criteria for Radiation Rate, Radiation Type, and Dose Distribution Type are the same for ORNL, as for other site profiles. Maximizing internal dose is assigned with the use of ORAUT-OTIB-0018, *Internal Dose Overestimates for Facilities with Air Sampling Programs*; or ORAUT-OTIB-0002, *Technical Information Bulletin: Maximum Internal Dose Estimates for Certain DOE Complex Claims*. The application of these OTIBs for the assignment of dose is consistent with other site profiles. External dose assumptions were consistent with those used in other site profiles. The default energies for beta, photon, and neutron exposure were >15 keV, 30–250 keV, and 0.1–2.0 MeV, respectively. The missed external dose is calculated using the MDL/2 calculation times the number of monitoring periods, and is entered as a lognormal distribution with a geometric standards deviation of 1.52. This is consistent with other site profiles.

The ORNL Occupational External Dose TBD provided Attachment 6A on page 76 to allow the dose reconstructor's selection of IREP energy groups by process location for beta-gamma exposures. Likewise, Attachment 6B on page 78 provides similar guidance by process location for neutron-to-photon ratios at ONRL facilities for 100 % occupancy. The LANL Occupational External Dose TBD (Widner 2005) applies an area-specific neutron energy distribution for years

after 1978. For years prior to 1980, the annual photon dose is multiplied by a neutron-to-photon ratio to obtain the neutron dose. The TBD (Widner 2005) has derived three neutron-to-photon ratios for the plutonium facilities, criticality experiments (> 50 m distant), and other operations. The SRS TBD distinguishes neutron energies and neutron-to-photon ratios for reactors, fuel fabrication, plutonium production, and radionuclide production and calibration (Scalsky 2005). The INEEL Occupational External Dose TBD (Rohrig 2004) considers the reactors, the processing plant, waste-handling operations, calibration sources, and uranium handling. Neutron energy specta and neutron-to-photon ratios for Pu-238 and Pu-239 operations are segregated at SRS (Scalsky 2005). The categories used in the LANL TBD (Widner 2005) lack the detailed analyses seen in other TBDs. Further evaluation of neutron-to-photon ratios should include more specific categories, including neutron sources (RaBe, Cf, etc.), accelerators, early subcriticality experiments, initiator development, and neutron spectra from alternate fissile materials.

There also is no mention of whether the background uranium is subtracted from the urinary bioassay results in the ORNL Occupational Internal Dose TBD (Bollenbacher et al. 2006, pg. 19), but the LANL Occupational Internal Dose TBD (Argall 2004, pg. 29) states that the background uranium is subtracted from the bioassay results. SC&A is concerned with what appears to be an inconsistency in how the excretion of naturally occurring uranium is handled in the dose reconstruction between site profiles.

There is discussion in the Occupational Internal Dose TBD (Bollenbacher et al. 2006) of the levels of naturally occurring environmental uranium and the ratios of isotopes. However, it is not clear how NIOSH is going to handle this with regard to levels seen in urinary and fecal excretion and the bioassay monitoring data. Section 5.2.3.3, page 19, states that, “Plots of the observed uranium excretion distributions for U-234, U-238, and total uranium are provided below.” SC&A, however, fails to find these data in the document. There also is no mention of whether the background uranium is subtracted from the urinary bioassay results in the ORNL Occupational Internal Dose TBD (Bollenbacher et al. 2006, pg. 19), but the LANL Occupational Internal Dose TBD (Argall 2004, pg. 29) states that the background uranium is subtracted from the bioassay results. SC&A is concerned with what appears to be an inconsistency in how the excretion of naturally occurring uranium is handled in the dose reconstruction between site profiles.

SC&A is likewise concerned with the conflicting assumptions for solubility classification of uranium in between the ORNL Site Profile (Bollenbacher et al. 2006) and the LANL Site Profile (Argall 2004). The ORNL TBD states that the default to be used in dose reconstruction should be Type S (Table 5-2). The LANL Internal Dose TBD (Argall 2004) recommended Type M. The ORNL Internal Dose TBD does not address the Integrated Modules for Bioassay Analysis (IMBA) NIOSH Phase I database USDOE /Version 1.0.42, Tables 5-11 and 5-12, for isotopic composition for uranium. SC&A is concerned over some of these inconsistencies shown by NIOSH between site profiles.

The External Dose TBDs for Y-12 (Kerr 2006), SRS (Scalsky 2005), and Hanford (Fix 2004) base their default exposure geometry on the compensability or noncompensability of the claim. The MCW (Westbrook 2005) and RFP (Furman and Lopez 2004) TBDs based the default exposure geometries on job titles. The LANL (Widner 2005), ORNL, and INEEL (Rohrig 2004)

TBDs default to 100% AP geometry. Further evaluation of the exposure geometry for photon and neutron exposure should be evaluated for ORNL workers to determine if this is appropriate for all ORNL workers.

The ORNL External Dose TBD does not provide clear guidance on when to assign missed neutron dose, except to recommend that it be assigned when neutron exposure is expected. In the LANL, SRS, Hanford, and additional site profiles, the basis for assigning missed neutron dose is the work location and/or the existence of neutron dosimetry during another period of time. In the case of LANL, the neutron exposures from co-workers were also considered an indicator of potential neutron exposure (Widner 2005).

The current Occupational External Dose TBD (Burns and Mohrbacher 2004) states it does not address reconstruction of skin dose. Shallow dose at ORNL is determined by the procedure outlined in ORAUT-0TIB-0017 (see Attachment 3).

The LANL External Dose TBD (Widner 2005) has developed facility-specific neutron energy distributions and neutron-to-photon ratios. Furthermore, neutron-to-photon ratios have been developed for worker groups that received neutron exposure. The SRS TBD distinguishes neutron energies and neutron-to-photon ratios for reactors, fuel fabrication, plutonium production, and radionuclide production and calibration (Scalsky 2005). The INEEL Occupational External Dose TBD (Rohrig 2004) considers the reactors, the processing plant, waste-handling operations, calibration sources, and uranium handling. Neutron energy spectra and neutron-to-photon ratios for Pu-238 and Pu-239 operations are segregated at SRS (Scalsky 2005).

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