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ADVISORY BOARD ON

RADIATION AND WORKER HEALTH

National Institute for Occupational Safety and Health

REVIEW OF THE SUMMARY SITE PROFILE FOR THE SANDIA NATIONAL LABORATORIES AT LIVERMORE, CALIFORNIA

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ACRONYMS AND ABBREVIATIONS

Advisory Board or ABRWH	Advisory Board on Radiation and Worker Health
AEC	U.S. Atomic Energy Commission
AMAD	Activity median aerodynamic diameter
ANL	Argonne National Laboratory
AP	Anterior-Posterior
ARG	Accident Response Group
CATI	Computer Assisted Telephone Interview
CDHS	California Department of Health Services
CEP	Controls for Environmental Pollution
CFR	*Code of Federal Regulations*
Ci	curie
CRF	Combustion Research Facility
D&D	decontamination and decommissioning
DOD	Department of Defense
DOE	U.S. Department of Energy
DOE-AL	Department of Energy – Albuquerque
DOELAP	Department of Energy Laboratory Accreditation Program
dpm	disintegrations per minute
DU	Depleted Uranium
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
ESE	entrance skin exposure
EU	Enriched Uranium
FDA	Food and Drug Administration
g	gram
GPS	Gas Purification System
HEPA	High Efficiency Particulate Air
HHS	Health and Human Services
HTO	tritiated water vapor
IAAP	Iowa Army Ammunition Plant
ICRP	International Commission on Radiological Protection

IREP	Interactive RadioEpidemiological Program
KCP	Kansas City Plant
L	liter
LANL	Los Alamos National Laboratory
LAT	Lateral
LLNL	Lawrence Livermore National Laboratory
LOD	Limits of Detection
keV	kiloelectron volt
kVp	peak kilovoltage
mA	milliamperes
MAP	Mixed Activation Products
MDA	Minimum Detectable Amount
MDL	Minimum Detection Limit
MeV	megaelectron-volt, 1 million electron-volts
MFP	Mixed Fission Products
mR	milliRoentgen
mrem	millirem
NIOSH	National Institute for Occupational Safety and Health
NTA	Nuclear Track Film Type A
NTS	Nevada Test Site
NU	Natural Uranium (or U-nat)
OBT	Organically-bound Tritium
ORAUT	Oak Ridge Associated Universities Team
OTIB	Oak Ridge Associated Universities Team Technical Information Bulletin
PA	Posterior-Anterior
pCi	picocurie
PNNL	Pacific Northwest National Laboratory
POC	Probability of Causation
PPG	Pacific Proving Ground
ppm	parts per million
R&D	Research and Development
RadCon	Radiological Control

RDC	Radiation Detection Company
RFP	Rocky Flats Plant
RESL	Radiological and Environmental Sciences Laboratory
SC&A	S. Cohen & Associates, Inc.
SDI	Strategic Defense Initiative
SEC	Special Exposure Cohort
SLL	Sandia Laboratories – Livermore
SNL	Sandia National Laboratory
SNL NM	Sandia National Laboratory in Albuquerque, New Mexico
SNL CA	Sandia National Laboratory in Livermore, California
SRDB	Site Research Database
SRS	Savannah River Site
SSTB	Salton Sea Test Base
STC	Special Tritium Compound
TBD	Technical Basis Document
TIB	Technical Information Bulletin
TLD	Thermoluminescent dosimeter
TLV	Threshold Limit Value
TRL	Tritium Research Laboratory
TTR	Tonopah Test Range
TWA	Time-weighted Average
U-nat	Natural Uranium (or NU)
VERS	Vacuum Effluent Recovery System
yr	Year

1.0 EXECUTIVE SUMMARY

This draft report presents the S. Cohen and Associates' (SC&A's) evaluation of the National Institute for Occupational Safety and Health (NIOSH) *Site Profile for the Sandia National Laboratories in Livermore, California (SNL CA)* (ORAUT 2007a), which was issued as a summary site profile document. This work was authorized by the Advisory Board on Radiation and Worker Health (Advisory Board) and by SC&A's Project Officer during the full Board meeting held in Augusta, Georgia, on December 16–18, 2008. This review was conducted during the period February 2009 through February 2010. It was conducted in accordance with the Board's "Data Access and Interview Procedures," (ABRWH 2009a) as well as Board-approved SC&A procedures for the conduct of site profile reviews (SC&A 2004).

Sandia National Laboratory (SNL) originally established a facility in Albuquerque, New Mexico, in 1949. At the direction of the Atomic Energy Commission (AEC), Sandia was asked to establish a second facility in Livermore, California, in 1956. Construction was completed in 1959. Its mission was to provide ordnance engineering support to Lawrence Livermore National Laboratory (LLNL). The Sandia National Laboratory – Livermore (SNL CA) facility was originally a 75-acre lot on East Avenue, across the road from LLNL. In 1970 and 1979, SNL CA acquired an additional 86 acres and 24 acres, respectively, for a total of 185 acres. In 1985 and 1986, there was an additional 228 acres added for security purposes. Two test sites, Tonopah Test Range and Kauai, are operated under Sandia. The current missions of Sandia National Laboratories are (Loeber 2002, Sandia 1983):

- Conduct research and engineering activities
- Conduct experiments on nuclear weapons effects
- Design non-nuclear components and perform related system engineering
- Manufacture selected non-nuclear components
- Modify weapons to meet new requirements
- Provide safety and reliability assessments of the stockpile, including verification of the integrity of weapons in the stockpile
- Develop and apply advance technologies to protect nuclear material

Nuclear ordnance work includes "safing;" command and control; arming, fusing, and firing systems; aerodynamics and structures; and related testing and instrumentation. After weapons are in the stockpile, quality assurance evaluators periodically obtain samples and test them in the laboratory and the field to assure that the components continue to operate safely and reliably. Sandia personnel are involved with a nuclear weapons program from its inception through retirement from the stockpile. Sandia also began participating in a national effort to develop new or improved sources of energy. Although numbers of employees for all years are not available, the employee population from 1968 to 1982 ranged from 868 to 1,088.

A site visit was conducted from June 8–12, 2009, encompassing a comprehensive document review and site expert interviews. A subsequent telephone interview was conducted on June 28,

2009. Interviews were conducted with 10 former and current SNL CA and SNL NM workers, including personnel from radiological control (RadCon) and dosimetry; weapons program development, design, and testing; environmental monitoring and waste management; and other Research and Development (R&D) programs. The purpose of these interviews was to hear first-hand accounts about past radiological control and personnel monitoring programs, and site operations.

This draft report was prepared at the request of the Advisory Board and provides an evaluation of ORAUT-TKBS-0053, *Summary Site Profile for Sandia National Laboratories in Livermore, California*, Rev. 00 (ORAUT 2007a). As part of our evaluation, SC&A also reviewed other documents that were considered relevant, including the following:

- Special Exposure Cohort (SEC) petition documentation for SNL CA
- Relevant technical information bulletins (TIBs)
- Select documents that were referenced in the SNL CA site profile
- Documents contained in the NIOSH Site Research Database (SRDB)
- Documents retrieved from data captures at SNL NM and SNL CA
- Other site profiles providing input to the SNL CA site profile

The review found that the Summary Site Profile document for SNL CA (ORAUT 2007a) does not provide adequate and sufficient information to guide dose reconstruction for a number of critical sources of historic internal and external exposures to SNL CA personnel. The site profile fails to address the adequacy and completeness of the SNL CA internal and external personnel monitoring data, especially that received during offsite visits or assignments. Bioassay monitoring for isotopes other than uranium and tritium is lacking, although there was potential exposure to other radionuclides both onsite and offsite. From a preliminary review of available SNL CA records and interviews with SNL CA personnel, there is sufficient reason to question the completeness, accuracy, and accessibility of bioassay records. The review identified gaps in claimant-specific dosimetry data, a lack of direction on where to find other sources of dosimetry data, and a lack of direction for the assignment of missed external and internal dose for workers potentially exposed to radiation. The site profile does not mention the availability or applicability of external or internal coworker models.

1.1 SUMMARY OF PRIMARY FINDINGS

A summary of SC&A's findings for the SNL CA site profile is presented below. The findings are detailed in Section 3 of this report.

Finding 1: Lack of Characterization of Offsite Worker Activities

There is evidence that many SNL CA workers also worked at other facilities within the weapons complex, using SNL CA as their home office (referred to here as "offsite worker" activities). However, the SNL CA site profile provides only minimal discussion with respect to those activities. The site profile would benefit from (1) a discussion of offsite work activities, (2) references to other technical basis documents (TBDs), as appropriate, (3) consideration of the completeness of records provided for exposures during offsite activities, and (4) treatment of doses potentially received by the SNL CA workers (which, in many cases, may have exceeded doses from onsite activities). Little or no external and internal exposure data exists for those individuals who traveled offsite and were potentially exposed to tritium, plutonium, uranium, thorium, mixed fission products (MFPs), mixed activation products (MAPs), and other radionuclides.

Finding 2: Incomplete and Unclear External and Internal Monitoring Data Makes Their Use in Dose Reconstruction Difficult

In a preliminary review of claimant files, incomplete, inaccurate, and redundant data was found. As a general rule, the dose reconstructor uses the data in the claimant file and default assumptions in the site profile to assign doses. Protocol does not require them to consult other sources of radiation exposure data, such as processing or analysis logs, bioassay result lists, or log sheets that may contain results. Radiation exposure information provided for claimants contain monitoring gaps, including periods where all personnel onsite were assigned dosimetry. Internal monitoring data is limited in claimant files, but may be found in the medical files where such information is often available. In order to obtain a complete monitoring record, additional data is available on the SRDB for use, but may be absent from the actual claimant files. The site profile does not provide guidance to the dose reconstructor on consulting these additional sources, which are sometimes the only source of monitoring data available for the worker. Furthermore, there are no internal or external dosimetry coworker models or alternative methodologies proposed for the assignment of dose to individuals who were monitored, but for whom data is missing or erroneous. Offsite monitoring data is extremely limited in claimant files, and requests for data from the visited sites is completely dependent upon input provided by the claimants in the Computer-Assisted Telephone Interviews (CATIs), placing an undo burden on the claimant (energy employees and survivors) to recall sites visited during employment at SNL CA.

Finding 3: Absence of Internal Dosimetry Personnel Monitoring for Radionuclides other than Tritium and Uranium

The site profile incorrectly considers internal dose from only tritium and depleted uranium (DU) at SNL CA. To some extent, SNL CA handled numerous other radionuclides, including thorium, thorium daughters, radium, radium daughters, enriched uranium (EU), MFPs, and MAPs. The quantity and details of handling are not readily available and require further investigation. The absence of an internal monitoring program for radionuclides other than tritium and uranium can lead to potential missed dose for onsite activities involving these other radionuclides. Additional information on processes involving these materials may only be available in classified documentation. Internal exposures were as likely, if not more likely, for activities Sandia personnel conducted at other DOE Complex sites. Potential exposures to radionuclides encountered at other sites include plutonium, thorium, MFPs, and MAPs. The limited tritium and uranium monitoring implemented at SNL CA is not adequate for detection of these other radionuclides, assuming any uptakes occurred. Furthermore, information obtained from other DOE sites for Sandia workers does not typically include internal monitoring data. SNL NM has also not been able to locate internal monitoring data for workers monitored at sites other than SNL CA, with exceptions for only a few facilities and time periods.

Finding 4: External Monitoring Program, as Implemented at SNL CA, is Not Adequately Characterized

There is a need to conduct further research on external dosimetry prior to 1989 to better understand the details and capabilities of the dosimetry systems implemented. Without sufficient information on the dosimetry technology, calibration methods, dose calculation algorithms, and adjustments to recorded doses, the development of correction factors, uncertainty, and bias factors is not defensible. Some dosimetry systems used at SNL CA had inadequate discrimination between beta, photon, and neutron exposures, yet exposure reports from this period include breakdowns of penetrating and non-penetrating doses. Assumptions regarding radiation energy distributions encountered in the field are not based on documented field measurements or other objective data. The SNL CA site profile attempts to compensate for its lack of dosimetry program data by adopting measurement uncertainty estimates from the Hanford site profile. The selection of these values requires further justification, given the numerous uncertainties related to dosimetry technology, calibration, processing, and recording practices, and differences in exposure conditions between Hanford and SNL CA. There are additional uncertainties associated with the assignment of missed dose, since the minimum detection limits (MDLs) and exchange frequencies were estimated and cannot be determined from records. This concern is confounded by the absence of annual or cycle processing data and the reliance on cumulative data in many claimant files.

Finding 5: Lack of Response of Nuclear Track Type A (NTA) Film to Low-Energy Neutrons, and Discrepancies in the Neutron Source Calibration

The site profile does not specifically address the subject of NTA film neutron energy threshold. NTA film decreases in response starting at neutron energies below 1 MeV, and is almost completely insensitive to neutrons below 0.5 MeV (ORAUT 2007a); therefore, radiation fields containing an appreciable percentage of the total dose equivalent due to neutron exposures below 1 MeV must be evaluated carefully, with attention given to the dose missed resulting from this threshold effect. The site profile should address this issue, and make clear and technically sound recommendations to compensate for the incomplete neutron doses recorded by NTA film and contained in the dose of record.

Finding 6: Lack of Consideration of Special Tritium Compounds

The site profile fails to adequately consider potential uptakes of special tritium compounds (STCs). Special tritium compounds were generated as a result of dynamic activities conducted at the Tritium Research Laboratory (TRL). Uranium and palladium tritide beds were used. Special research was conducted to study microstructures of metals and evaluated the effects of pressure, temperature, and concentration on diffusion or permeation of tritium gas into metals. Special tritium compounds resulted as a byproduct of reactivity, diffusion, and permeation of handling of large quantities of tritium gas and tritiated water in structural material and routinely used oils and solvents. The site profile assumes HTO for calculation of tritium dose, although other forms of tritium were present. Assumption of an intake of HTO in place of STCs can underestimate dose by orders of magnitude, depending on the type of STC and organ of concern. Currently proposed approaches developed by NIOSH for estimating dose from STCs rely on the use of urine bioassay results in concentration (e.g., µCi/L) and the ability to identify workers exposed to STCs. The site profile should discuss in detail how they will estimate dose from STCs, particularly those compounds not readily disassociated to soluble compounds in the body. Furthermore, the solubility type assigned for uranium tritide should be consistent with available literature and assumptions made in other site profiles and dose reconstruction documentation.

Finding 7: Assumptions for Uranium Dose Assessment are Not Claimant Favorable

The detection limit assumed for uranium urinalysis analyzed by fluorometry appears to be too low in comparison with detection limits reported elsewhere in the industry for this procedure. Detection limits should be re-evaluated or validated with SNL NM and other bioassay providers to ensure that they are appropriate. Defaulting to DU for conversion of bioassay in units of mass concentration (µg/l) to activity, when the site handled NU and EU, would result in an under-estimation of dose for those individuals exposed to normal or EU. Uranium urinalysis samples collected from Controls for Environmental Pollution (CEP) (1990–1993, as defined in the site profile, and 1992–1994 as defined by the SNL NM contract) is suspect and cannot be used for the determination of uranium dose or for inclusion in a coworker model. The solubility assumption for UO_2 should reflect current literature, and take into account the potential that a fraction of this material may behave like Type M rather than Type S material. The solubility for uranium tritide is listed as Type S material, whereas uranium tritide is actually a Type F material. This correction should be reflected in former, as well as current, dose reconstructions.

1.2 OPPORTUNITIES FOR IMPROVEMENT

While the TBD provided some detailed information concerning the history, operational developments, and facilities at SNL CA, there was insufficient in-depth development in many areas to support adequate dose reconstruction recommendations. Some of these areas are:

- Different types/sources of radiation fields and their potential exposure to workers
- Dosimetry systems, changes, and associated problems
- Accuracy, availability, and adequacy of external dosimetry and bioassay records
- Data integrity of dose records as record systems changed
- Coworker internal and external dose data and/or dose reconstruction recommendations for under-monitored or unmonitored workers

The SNL CA site profile was developed without the full benefit of the worker outreach efforts described under OCAS-PR-012, *Worker Outreach Program* and its predecessor ORAUT-PROC-0097, *Conduct of the Worker Outreach Program* (ORAUT 2005e), and implemented in ORAUT-PROC-0031, *Site Profile and Technical Basis Document Development* (ORAUT 2007f). As a result, there are gaps in the characterization of radiological exposure for SNL CA workers, which were confirmed during SC&A site expert interviews.

2.0 SCOPE AND INTRODUCTION

The review of the *Summary Site Profile for Sandia National Laboratories in Livermore, California* (ORAUT 2007a) was authorized by the Advisory Board at its December 16–18, 2008, meeting in Augusta, Georgia, and conducted during February 2009–February 2010 by a team of health physicists and technical personnel. Pertinent records reviewed included both classified and unclassified documents located at SNL CA and SNL NM. This review was performed in accordance with the *Data Access and Interview Procedure* (ABRWH 2009a), which provides for appropriate onsite coordination and data access protocols in conjunction with the Advisory Board, NIOSH, and DOE, and the *Department of Energy Classification Review of Documents* (ABRWH 2009b), and provides for appropriate security clearance reviews.

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

2.1 REVIEW SCOPE

The Advisory Board on Radiation and Worker Health (Advisory Board) is mandated to conduct an independent review of the methods and procedures used by NIOSH and its contractors for dose reconstruction. As a contractor to the Advisory Board, SC&A supports 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 TBD related to historical occupational exposures at SNL CA, ORAUT-TKBS-0053, *Summary Site Profile for Sandia National Laboratories in Livermore, California* (ORAUT 2007a).

To date, the site profile has not been supplemented by site-specific TIBs, but there are several generic TIBs that provide additional guidance to the dose reconstructor. Two SNL CA-specific SEC petition evaluation reports were issued in 2007, which serve to inform this review:

- SEC-00059, *SEC Petition Evaluation Report, Sandia National Laboratories – Livermore, Petition SEC-00059*, Rev. 00, March 26, 2007 (NIOSH 2007a).

- SEC-00059 Addendum, *SEC Petition Evaluation Report – Addendum, Sandia National Laboratories – Livermore, Petition SEC-00059-Addendum*, Rev. 00, September 6, 2007 (NIOSH 2007b).

- ORAUT-OTIB-0006, *Technical Information Bulletin: Dose Reconstruction from Occupationally Related Diagnostic X-ray Procedures*, Rev. 03-D, December 21, 2005 (ORAUT 2005a).

- ORAUT-OTIB-0066, *Calculation of Dose from Uptakes of Special Tritium Compounds*, April 26, 2007, (ORAUT 2007e).

- ORAUT –TKBS-0036-4, *Lawrence Livermore National Laboratory – Occupational Environmental Dose*, October 7, 2005 (ORAUT 2005b).

- ORAUT-TIB-0055, *Technical Basis for Conversion from NCRP Report 38 Neutron Quality Factors to ICRP Publication 60 Radiation Weighting Factors for Respective IREP Input Neutron Energy Ranges*, June 5, 2006 (ORAUT 2006a).

SC&A also reviewed other pertinent documents, including those cited on the SRDB. SC&A has critically reviewed the SNL CA TBD, as well as supplementary and supporting documents, against the following three evaluation criteria:

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

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

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

The SNL CA site profile document serves as site-specific guidance document to be used in support of dose reconstructions for claimants. It provides the health physicist who conducts the 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 TBD can support dose reconstruction decisions.

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

2.2 ASSESSMENT CRITERIA AND METHODS

SC&A was charged with evaluating the approach set forth in the site profiles that are used in the individual dose reconstruction process. These documents are reviewed for their completeness, technical accuracy, adequacy of data, consistency with other site profiles, and compliance with the stated objectives, as defined in *SC&A Standard Operating Procedure for Performing Site Profile Reviews* (SC&A 2004). This review is specific to the SNL CA site profile; however, items identified in this report may be applied to other facilities, especially facilities with similar source terms, exposure conditions, and mobile workforces. 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 (SC&A 2004).

2.1.1 Objective 1: Completeness of Data Sources

SC&A reviewed the site profile with respect to Objective 1, which requires SC&A to identify principal sources of data and information that are applicable to the development of the site profile. The two elements examined under this objective are (1) determining if the site profile made use of available data considered relevant and significant to the dose reconstruction, (2) investigating whether other relevant/significant sources are available, but were not used in the development of the site profile, and (3) determining how worker input was considered in the development of the site profile.

2.1.2 Objective 2: Technical Accuracy

Objective 2 requires SC&A to perform a critical assessment of the methods used in the site profile to develop technically defensible guidance or instructions, including evaluating field characterization data, source term data, technical reports, standards and guidance documents, and literature related to processes that occurred at SNL CA. The goal of this objective is to analyze the data according to sound scientific principles, and then evaluate this information in the context of dose reconstruction.

2.1.3 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. An important consideration in this aspect of our review of the site profile is the scientific validity and claimant favorability of the data, methods, and assumptions employed in the site profile to fill in data gaps.

2.1.4 Objective 4: Consistency among Site Profiles

Objective 4 requires SC&A to identify common elements within site profiles completed or reviewed to date, as appropriate. In order to accomplish this objective, the SNL CA TBD was compared to other TBDs, particularly those referenced in the site profile and those related to frequently visited facilities. This assessment was conducted to identify areas of inconsistencies and determine the potential significance of any inconsistencies with regard to the dose reconstruction process.

2.1.5 Objective 5: Regulatory Compliance

Objective 5 requires SC&A to evaluate the degree to which the site profile complies with stated policy and directives contained in 42 CFR Part 82. In addition, SC&A evaluated the TBD for adherence to general quality assurance policies and procedures utilized for the performance of dose reconstructions.

SC&A's draft report and preliminary findings will subsequently undergo a multi-step resolution process. Prior to and during the resolution process, the draft report is reviewed by the DOE Office of Health, Safety, and Security to confirm that no classified information has been incorporated into the report.

All review comments apply to Rev. 00 of the SNL CA site profile document, which is the most recently published version. Site expert interviews were conducted with former and current SNL CA site workers to assist SC&A in obtaining a comprehensive understanding of the radiation protection program, site operations, and historic exposure experience.

Attachment 1 to this report provides a summary of the collective interviews conducted by SC&A during the course of this review, and approved by interviewees. Although limited in number, the interviewees included radiological control (RadCon) operations and dosimetry, engineering and technical staff, and support workers that worked at the site from 1959 to present. Secure interviews were conducted onsite by Robert Bistline (SC&A/Saliant, Inc.) and Kathryn Robertson-DeMers (SC&A/Saliant, Inc.), in Livermore, California, on June 8–12, 2009. A follow-up telephone interview was conducted on June 28, 2009. Additional interviews were conducted with staff members of SNL in Albuquerque who were knowledgeable of the dosimetry program and history of SNL CA.

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) Vertical Issues (Findings Identified in the SNL CA Site Profile)
(4) Overall Adequacy of the Site Profile as a Basis for Dose Reconstruction.

Based on the issues raised, SC&A prepared a summary list of findings, which are presented in the Executive Summary. Issues are designated as "Primary Findings" if SC&A believes that they represent deficiencies that need to be corrected and which have the potential to have a substantial impact on at least some dose reconstructions. Issues can also be designated as Secondary Findings if they simply raise questions, which, if addressed, would further improve the site profile and may possibly reveal deficiencies that will need to be addressed in future revisions of the site profile. Detailed analyses of the primary and secondary findings are provided in Section 3.0 of this report.

3.0 FINDINGS IDENTIFIED IN THE SANDIA NATIONAL LABORATORY, LIVERMORE, CALIFORNIA SITE PROFILE

Findings are categorized into Primary and Secondary Findings. Those designated as Primary Findings are likely to have an impact on the organ dose and the dose reconstruction outcome, while Secondary Findings are provided primarily to improve the quality of the site profile.

3.1 FINDING 1: LACK OF CHARACTERIZATION OF OFFSITE WORKER ACTIVITIES

SNL CA technical personnel frequently traveled to other DOE sites where there was a potential for radiation exposure. The site profile has not adequately characterized the potential exposures received by these SNL CA workers as a result of exposures to radiation from these site visits. The site profile stresses that although SNL CA was responsible for design and engineering of weapons, the production of parts and final weapons was completed at other DOE complex sites. The site description states (ORAUT 2007a, pg. 11):

> *SNL/CA was to engineer, or weaponize, the nuclear weapons package designed by LLNL; production of parts and final weapons was accomplished at other weapons complex sites.*

This gives the impression that radiation exposure was limited to those radioactive materials existing at the site in Livermore, California. To understand the potential for exposure, a more indepth understanding of the work conducted by Sandia personnel, especially technical staff, is needed.

SNL CA was established to provide ordnance engineering support to LLNL in 1956. The process for weapons development involved distinct phases, which allude to the types of activities in which workers were involved throughout the weapons cycle, as follows.

> *The DOE laboratories and production plants are responsible for the design, development, testing and certification, maintenance, stockpile surveillance, and retirement of the warhead. These activities occur in seven phases:*
>
>> *Phase 1 evaluates new concepts and advances in technology for possible application to nuclear weapons.*
>>
>> *Phase 2 involves a technical and cost feasibility study examining the military requirements and cost effectiveness of a new weapon system.*
>>
>> *Phase 3 commences when the DoD [Department of Defense] decides to proceed with a weapon system acquisition. It involves the engineering development work for a warhead, including overall design definition and component development.*

> *Phase 4 is production engineering. Development is completed and thousands of drawings are produced. Manufacturing and assembly processes are established.*
>
> *Phase 5 begins with first production. These first units are rigorously checked in the laboratory and in the field. Ancillary equipment and manufacturing are completed during this phase.*
>
> *Phase 6 is quantity production of the weapon and maintenance of the weapon in the stockpile. Upgrades or modifications may be performed during Phase 6 if required. Stockpile evaluation sampling and surveillance continue throughout stockpile life.*
>
> *Phase 7 retires the weapon from the stockpile and reclaims nuclear material and reusable parts.* (Loeber 2002)

Sandia personnel were involved with a nuclear weapons program from its inception through retirement from the stockpile. Nuclear ordnance work conducted by SNL CA employees included safing; command and control; arming, fusing, and firing systems; aerodynamics and structures; and related testing and instrumentation. After weapons were in the stockpile, quality assurance evaluators periodically obtained samples and tested them in the laboratory and field to assure that the components continued to operate safety and reliably (Furman 1990). As a result of these and other testing activities, employees came into contact with radioactive material, starting with Phase 3 of the process and continuing through Phase 7, either at SNL CA or as visitors to R&D and/or production facilities. Potential exposure exists not only at other DOE complex sites, but also at military installations throughout the world.

Sandia established a permanent installation at the LLNL Site 300 in September 1957. SNL CA participated in testing at Sandia Corporation testing sites, including the Tonopah Test Range (TTR), the Salton Sea Test Base (SSTB), and test facilities located at SNL NM (SNL CA no date).

> *Test activities have always provided a major role in the weapons projects of 8100* [A directorate of SNL established in Livermore, California to perform weaponry work in support of the University of California Radiation Laboratory]. *The activities included providing the environmental test capabilities at Livermore, and the coordination and conduction of tests at LLNL's Site 300, at Sandia-Albuquerque, and at most of the Department of Defense test ranges.*

SNL operates the Tonopah Test Range for the DOE. TTR covers 525 square miles within the boundaries of the Nellis Air Force Base Bombing and Gunnery Range, and was established in 1956 to function as a complex outdoor laboratory for testing weapons systems. The first drop test was conducted on February 8, 1957, and Rocket Testing began July 27, 1957. During the 1960s, there were about 500 tests conducted each year at TTR. Participation in activities at TTR was inclusive of SNL CA personnel. Although the SNL NM site profile includes a section on potential exposures at TTR, SSTB, and Coyote Canyon, a similar discussion is absent from the

SNL CA site profile. Exercises at SSTB involved recovery training. Potential exposures to Am-241, Pu-238, and Pu-239/Pu-240 were identified in the SNL NM TBD (ORAUT 2007b) as a result of the Clean Slate operation at TTR. Furthermore, in the SC&A review of the SNL NM TBD (ORAUT 2007b), uranium was identified as a potential exposure hazard at TTR and SSTB.

In addition to the above test activities, SNL CA staff participated in weapons testing at NTS, the PPG, and other continental tests associated with the Plowshare program. During weapons testing, responsibilities of scientists and engineers from SNL NM and SNL CA included "the determination of the sizes of nuclear devices to be detonated, how deep they should be buried, blast-safety studies, arming and firing of the devices, the resulting craters, and other blast phenomena" (SNL CA no date). In cooperation with the military, they conducted weapons effects studies to evaluate the effect of radiation on equipment. While Sandia personnel were involved in the arming and firing during most weapons tests, specific tests mentioned by claimants included Diesel Train (December 8, 1969), Diana Mist (February 11, 1970), Mint Leaf (May 5, 1970), and Dido Queen (August 5, 1973). Events Camphor (June 1971) and Cypress (February 1969) were SNL-sponsored radiation effects tests. In addition to their involvement with nuclear weapons tests at NTS, SNL CA participated in experiments conducted to assure the safety of weapons during shipment and storage.

Sandia's responsibility in supporting the Pacific tests included (SNL CA no date):

> *(1) Fusing and firing systems for certain test devices.*
> *(2) Telemetry instrumentation in rockets and other test devices.*
> *(3) Meteorology and microbaragraphics studies.*
> *(4) Tracking radar and tracking mounts for optical instruments.*
> *(5) Assistance in assembling and logical support of the actual test devices.*
>
> *In Livermore, the activity was enormous with everyone involved in the design, fabrication, shipping, scheduling, and movement of equipment to the test area.*

SNL CA personnel were involved in Project Dominic, the last atmospheric test series conducted by the United States in 1962. This effort was conducted in the Pacific near Christmas Island and at Johnson Island, and included bomb drops, rocket launched high-altitude nuclear bursts, and submarine-launched tests (SNL CA no date). Many employees from Livermore spent several months away from home in the Pacific during this test series.

The site profile acknowledges that a number of Sandia personnel traveled to other DOE complex sites to conduct work activities; however, it fails to acknowledge the extent of travel by technical and support staff to DOE production and Department of Defense (DOD) facilities, where there was a potential for exposure to radiation. Other DOE Complex facilities visited by SNL CA employees, as mentioned in site expert and claimant interviews, included, or in the case of active facilities, include visits to SNL NM, the Mound Plant, the Rocky Flats Plant (RFP), the NTS, the PPG, TTR, the Pantex Plant, the Y-12 Plant, LLNL (including Site 300), the Medina Plant, the Clarksville Plant, Iowa Army Ammunition Plant (IAAP), the Pinellas Plant, the Kansas City Plant (KCP), the Savannah River Site (SRS), Argonne National Laboratory (ANL), Pacific Northwest National Laboratory (PNNL), Los Alamos National Laboratory (LANL), and military installations. As a part of a smaller effort to improve the uranium enrichment process, some SNL CA employees visited the gaseous diffusion plants. Based on site expert interviews, review of documentation, and review of CATIs, visits could last from a day to several months. Experts indicated in some situations that they visited other sites multiple times. In some cases, claimants mentioned involvement in incidents while at other sites.

For some SNL CA employees, activities at other sites required entry into radiological areas, and involved activities associated with handling and testing of components. Site experts indicated that entry or tours into production areas at these sites were not uncommon. The monitoring requirements were determined by the host site, and were limited primarily to external exposure and/or tritium exposure depending on the site. Follow-up monitoring for radionuclides encountered at host sites, but not routinely monitored at the SNL CA site, also was not done. Limited internal monitoring is available in the records collected for visits to other sites to date, and a majority of the potential internal radionuclides encountered during offsite visits are not included. The general consensus from site expert interviews was that the likelihood of radiation exposure was greater during offsite visits versus exposure they may have received at the SNL CA facility.

While the site profile acknowledges offsite visits by SNL CA workers, it has failed to acknowledge the frequency and extent of these visits and the potential for radiation exposure for some categories of workers received during these visits. The TBD does not reference other TBDs, consider the completeness of records provided for exposures during offsite activities, or consider the dose potentially received, which in many cases potentially exceeded exposures associated with onsite activities. There was a reliance on the host site to provide personnel monitoring serves to SNL CA visitors. SNL CA internal monitoring programs do not provide coverage of potential exposures to radionuclides encountered at other sites, including plutonium, thorium, MFPs, MAPs, and other radionuclides. Coverage of tritium and uranium exposure by the onsite internal monitoring program would be dependent upon the solubility of the tritium, the adequacy of the bioassay method, and the sample date relative to the exposure date. It is clear that the site profile would have benefited from input from a worker outreach meeting specifically addressing SNL CA activities, as offsite activities were raised frequently during site expert interviews with SC&A.

3.2 FINDING 2: INCOMPLETE AND UNCLEAR EXTERNAL AND INTERNAL MONITORING DATA MAKES THEIR USE IN DOSE RECONSTRUCTION DIFFICULT

Quality assurance evaluations on incoming data presented by DOE and its contractors are critical to the dose reconstruction process. In a preliminary review of claimant files, SC&A observed incomplete, inaccurate, and redundant data. Requests for claimant dosimetry data were made more than once to SNL NM; however, data provided to NIOSH for individual claimants contain significant data gaps for external monitoring and minimal internal monitoring data. Generic data, such as dosimeter processing logs or cumulative exposure summaries, were available in the SRDB to mitigate some gaps in claimant files; however, no direction is provided in the site profile requiring that dose reconstructors access these additional sources of dosimetry information. Some urinalysis data were available in the individual Medical files, but were not necessarily duplicated in the individual radiation exposure files. Again, generic lists and processing logs, including tritium and uranium bioassay data, are available on the SRDB; however, no direction is provided in the site profile requiring dose reconstructors to access these data. There is an absence of offsite monitoring data in the claimant files, requiring NIOSH to identify all offsite activities for a claimant and request data directly from visited sites. Finally, no internal or external dosimetry coworker models are available for the assignment of dose in cases where data are missing and personnel were involved in work with radioactive material. The subject of data completeness is considered in the following sections for external and internal monitoring records.

External Dosimetry

SC&A performed a preliminary review of data completeness, using claimant files and other data retrieved from Sandia on the SRDB. The external dosimetry records in the claimant data, which is the primary source of data for dose reconstruction, are incomplete. External monitoring data provided on claimants, which constitutes a majority of the data retrieved for SNL CA workers, were primarily from logbook or printout listings. This review of available claimant records was complicated by claimant files being poorly organized and often redundant (e.g., one claimant's file had six separate electronic documents providing redundant information on the worker's 1965 first quarter badge reading). A document that yielded more than one piece of claimant-specific data per page was a rare find. Some documents contained no internal identification of the time period represented or headings for the data columns. A dose reconstructor would have a tedious and time-consuming job extracting relevant exposure data from the claimant files that SC&A reviewed.

Gaps in Claimant File Monitoring Data

Documentation indicates that all personnel onsite were monitored from the establishment of SNL CA through 1970. A 1960 memorandum from R.L. Hanzel (SNL CA) to G.L. Rhodes (SNL CA) indicates that all personnel, including contractors and visitors, were badged at that time (Hanzel 1960).

> *At the present time, all Livermore Laboratory and on-site contractor personnel and all individuals who visit the Livermore Laboratory are issued film badges to determine accumulated individual radiation exposures received while on the premises. This policy has been in effect from the time the Sandia Corporation, Livermore Laboratory was established.*

The SEC petition evaluation report, post-dating the site profile, indicates that the practice of badging all personnel at SNL CA continued until 1970 (NIOSH 2007a).

> *From information in a memo dated October 6, 1965 and information available in annual dose summary reports, it can be concluded that until 1970, all personnel at SNL-L were badged (DeSelm, 1965; AEC, Various dates). After 1970, only employees working with or around radiation-generating devices or those that had*

the potential to exceed a pre-specified threshold were badged (ORAUT-TKBS-0053, Section 6.4.1.1 [ORAUT 2007a]*).*

The preliminary data review revealed gaps in the external monitoring data in claimant files during years when all personnel were reportedly monitored. Disregarding cumulative reports, such as a single line representing 1957–1965 or "lifetime" exposure, few data points prior to 1971 could be located in the selected claimant files. For example, one claimant's file contains only two quarterly badge results for the 10-year span from 1961 through 1970. In a 12-year span from 1959 through 1970, another claimant's file contains four quarterly badge results and two values that appear to be yearly totals. A third claimant file includes only 1 yearly total, 10 monthly badge results, and 4 quarterly results (less than 3 years worth of monitoring data) for the 11 year span from 1960 through 1970. Each of the claimant files reviewed also had data gaps after 1970. In some cases, data for a particular year is incomplete; in other cases, gaps of 1 to 5 years are interspersed with occasional results. It was not readily apparent that any of the workers were intentionally unmonitored due to changes in their work activities.

Dosimetry records form the primary basis for conducting dose reconstruction. A quality assurance review of the data received from the site is critical to ensuring appropriate and complete records are provided for consideration in the dose reconstruction process. The incomplete nature of the claimant files, and the resulting dose assignment techniques for large gaps in data are not adequately reflected in the site profile. The *Sandia National Laboratory, Livermore Special Exposure Cohort Petition* (Petition SEC-00059) raised issues associated with the availability of monitoring records and difficulty in collecting data for the period prior to 1989, but indicated subsequent data capture trips to SNL CA remedied the situation (NIOSH 2007b). Many of the cited data sources captured by NIOSH are generic logbooks and lists that are only available through the SRDB. These data sources are scattered and, although available, were not always duplicated in the individual claimant file. Direction is not provided in the site profile which directs the dose reconstructor to these data sources. A combination of the dosimetry data in the individual radiation exposure file, the medical file, and the generic logbooks and lists are required to compile a complete radiation exposure history for an individual. Consulting the SRDB generic dosimetry logbooks and lists will mitigate some, but not all gaps in the radiation exposure data for individuals.

Section 6 of the site profile does not reference or provide any coworker data for use in assigning doses to workers who should have been monitored, but were not monitored after the termination of site-wide badging. Given the observed gaps in the monitoring data, a coworker model or alternate methodology is needed to assign dose to unmonitored workers who should have been monitored during the era when the site did not badge all employees. Since gaps in the claimant records continue beyond this period, further evaluation of the completeness of individual monitoring data for radiation workers is necessary.

Uncertainties and Discrepancies in Records

In many cases, it is difficult to interpret dosimetry data present in the claimant files. One claimant had a monthly badge result for 1962 (the only result for the year). A comment in another document raised doubts about the validity of that result. Another claimant file listed a value for x-ray/gamma exposure for a particular month in 1971. The following page, a "Dosimetry Update Error Listing" for the same monitoring interval, listed the same value. It was not clear whether the value was an error or a correction. In several cases, reports that listed issue and return dates were missing entries for the month of return. Reviewers were not certain if these blanks represented badges that were not returned ("0" versus no result) or simple omissions in record keeping,

Several reports and records had blanks rather than zeroes for the majority of the workers listed. It appeared to be accepted practice to record, or to search computer records, for only positive results, letting the absence of data imply a negative result. One claimant had group annual exposure reports in his medical record covering each year from 1970 through 1985. The presentation of the claimant's data in these reports made it difficult to discern if the worker had been monitored during those years. The data row with the claimant's name was completely blank (no badge number, issue/return dates, current results, or year-to-date exposure); only the "prev" and "cum" rows contained values. Since specific monitoring results were located in other document files for several of these years, it appears that the claimant was monitored.

Contributing Factors

Specific dosimetry program concerns that may have contributed to data gaps might be gleaned from internal correspondence. According to Hanzel (1960), there was some concern that badge issuance and exchange were not centralized:

> *In general, the administrative and physical problems which must be coped with in maintaining such an extensive program arise from the fact that no single organization issues and exchanges film at the laboratory.*

Additional recordkeeping difficulties arose because the radiation exposure records were based on security badge numbers, which were not permanent identifiers. Hanzel (1960) goes on to say:

> *Some individuals have been issued two, three or even four security badge numbers during the past year, which has proven to be a troublesome records problem for both the Medical and Safety Section, responsible for administrating the film badge program, as well as the contractor providing the services.*

In addition, Hanzel (1960) noted that a significant fraction of workers (20%–25%) routinely failed to exchange their badges during the normal monthly exchange period.

Hanzel (1960) advocated reducing the external dosimetry program to workers and visitors who worked in specific areas where potential exposures of 30 mR to personnel existed. His suggestion that "the receipt, storage, issue of badges and record keeping involving fewer individuals could be more closely supervised" seems to imply that monitoring and documenting exposures for all personnel and visitors was too cumbersome to be effectively managed with available resources.

The external exposure data for individuals working onsite at SNL CA is incomplete. Claimant-specific dosimeter results from before 1970 (when documentation indicates that all personnel on site were monitored) were sparse within the claimant files reviewed by SC&A. The years after 1972 were better represented in the claimant files, but there appears to be gaps in these data, as well.

Internal Dosimetry Completeness

In the case of onsite workers, tritium bioassay was collected on a biweekly or weekly basis for workers routinely assigned to the TRL. Routine uranium samples were conducted for a small group of individuals associated with machining uranium. There was no routine bioassay program for other radionuclides handled at SNL CA. According to worker interviews, SNL CA sometimes collected bioassay from workers upon return from other DOE Complex facilities; yet records from these bioassay samples are not available. Site experts indicated that, due to releases at the Mound site, they were sampled upon return to SNL CA by Medical, but records do not reflect such sampling. SNL NM did not start to maintain internal dosimetry records for SNL CA until 1990 for tritium (ORAUT 2007a, pg. 43). For uranium bioassay records, the site profile states that all bioassay samples were sent to SNL NM for analysis starting sometime prior to 1968 (ORAUT 2007a, pg. 47); however, it is not clear whether SNL NM was responsible for maintaining records for these personnel, or they just sent the bioassay results back to SNL CA for them to maintain.

Based on a preliminary review of claimant files, it was found that little or no internal monitoring data exist in claimant files, and a majority of the data located for claimants are found in medical files. Bioassay data identified are limited to tritium and uranium urinalysis. Generic logs and lists of internal monitoring are available in various documents included in the SRDB, which may or may not be duplicated in the claimant files. As a general rule, the dose reconstructor uses data in the claimant file or default assumptions in the site profile to assign dose. The use of actual monitoring data is preferable to assignment of dose based on generic assumptions. Protocol does not require dose reconstructors to consult other sources of radiation exposure data, such as processing or analysis logs, bioassay result lists, or log sheets with results, which in the case of SNL CA, may contain additional monitoring data. The site profile needs to provide direction for consideration of these additional sources. There is a lack of offsite internal monitoring data available, including data requested from other sites as a result of site visits. Tritium data is available for some periods of time for LLNL, but this is the extent of offsite internal monitoring data identified by SC&A in claimant file reviews and on the SRDB. Further investigation is needed on the extent and availability of internal monitoring data and how this information will be compiled for complete monitoring histories.

The site profile does not mention the availability or applicability of coworker internal dose models for tritium and uranium, nor has SC&A identified a TIB providing a coworker model. In lieu of a coworker model, the site profile proposes to assign dose for gaps in internal monitoring data of workers potentially exposed to tritium and uranium, but not monitored, based on 10% of the airborne radionuclide concentration limits. It is prudent to review all available tritium and uranium bioassay data for use in the development of a coworker model, rather than basing internal dose on a fraction of the regulatory air concentration limits. This is contrary to the hierarchy of data defined for use in the dose reconstruction process. For those individuals with data gaps, or those who should have been monitored but were not, it would be advantageous to have a viable coworker model to use in the assignment of unmonitored dose.

Availability of Offsite Exposure Information

The SNL CA site profile gives the impression that host sites were requested to provide radiation exposure reports, and that SNL CA workers were directed to request internal and/or external monitoring if they entered a radiological control area (ORAUT 2007a, pg. 19).

> *When workers traveled to other locations, such as across the street to the LLNL site, the LLNL Site 300, or other non-SNL-operated sites, the host sites were to be requested to report exposures at those locations to the appropriate staff at SNL/CA or SNL/NM (SNL/CA – updated b). A response to the DOE site appraisal finding related to offsite dosimeters indicated that SNL/CA directed employees to "request internal and/or dosimetry, workplace monitoring, etc., if they must enter radiation controlled areas at the visited facility" in 1985 (Wallace 1988).*

Site expert interviews indicated that this policy was not well communicated to those involved in offsite visits, and that the host site determined the monitoring requirements. When workers visited other sites, they were sometimes assigned a dosimeter [i.e., film badge or thermoluminescent dosimeter (TLD)] by the visited site. It was noted that visitor data returned to NIOSH on claimants participating in offsite visits indicated that minimal or no data was located. This is true for workers who not only visited other DOE Complex sites, but those who entered into production areas and in some cases were involved in incidents. A review of the dosimetry records indicates that external data was provided to NIOSH for RFP, NTS, and Pantex Plant. Tritium data was present for some time periods from LLNL. Workers indicated they do not recall being told to request monitoring at a visited site, or to request that internal and external monitoring results be provided to SNL CA. Health Physics staff indicated that if dosimetry reports were requested from workers visiting other sites, they would be sent to SNL NM and not to SNL CA. It is important to note that visitor records are often stored separately from employee records and may require additional searches. Visitor or temporary status should be specified in requests to visited sites. Historically, there was no emphasis placed on providing visitor dosimetry results to the home site. Some facilities, such as the NTS, routinely sent visitor results, while others did not implement this practice routinely until it became a regulatory requirement. Tracking visitor dose is complicated when the home site does not incorporate visitor dosimetry data into individual-specific dosimetry files.

Although the site profile touches on offsite visits, it does not provide guidance on how to ensure all offsite dosimetry records are collected, and how to incorporate these potential exposures into the dose reconstruction process, <u>nor does the dose reconstruction process acknowledge the time spent by SNL personnel at other sites during established SEC periods</u>. NIOSH has a policy to request records from offsite visits if information is provided in the CATI regarding these visits. There is no specific question asking about offsite visits, so the claimant (both energy employees and survivors) must recall these visits and raise them as an additional comment in the CATI. A review of the CATIs and NIOSH follow-up requests for offsite exposure data indicate that dosimetry information from sites mentioned specifically in the CATI is requested by NIOSH for the visited site. If no information is specifically provided by the claimant, no information for offsite exposure is requested. In addition, it was noted that monitoring was not located for Sandia workers at a majority of the host sites. A brief review of exposure information retrieved for specific claimants and radiation exposure summary reports available on the SRDB indicate that most of the data were for external dose, with a limited amount of tritium data found for LLNL. A review of the claimant SNL CA dosimetry files indicated that in only a few circumstances was the offsite exposure data included in the SNL CA dosimetry file. In some cases, the monitoring dates and information did not correspond to the monitoring information available in dosimetry summary reports. Furthermore, it appears that dose information on offsite exposure available through the SRDB is not clearly inclusive of all dose received offsite; there was a disconnect between specific information provided in site expert interviews related to offsite visits, and exposure information available in either the SNL CA dosimetry file or the dosimetry information provided by the visited site.

Given the extent of offsite visits, the lack of monitoring data for such visits, and the potential for exposures at these sites, additional consideration of the potential impact of missed external and internal dose incurred by Sandia personnel during routine offsite visits to other facilities requires further treatment in the site profile, particularly where there was a potential for radiation exposure. The frequency and length of offsite visits, particularly for those sites with existing SEC status, requires further investigation and documentation. Reliance on claimant-provided information on offsite visits in the CATI is questionable at best, considering that there is no specific question on the CATI to solicit this information. Furthermore, survivor claimants may not have specific knowledge on offsite visits and activities. A validation of the completeness and adequacy of the visitor dosimetry data is needed, since workers indicate that it is possible most of their dose was received during offsite visits and visitor dosimetry data are not always reflected in the individual dosimetry files provided by Sandia. In addition, visitor dosimetry data are not being effectively retrieved from some DOE complex sites, indicating that the facilities are not doing complete dosimetry records recovery, or that personnel were not monitored effectively while visiting other sites.

3.3 FINDING 3: ABSENCE OF INTERNAL DOSIMETRY PERSONNEL MONITORING FOR RADIONUCLIDES OTHER THAN TRITIUM AND URANIUM

The SNL CA site profile failed to consider potential internal exposure from "other" radionuclides. The site profile indicates that the only radionuclides of concern for internal dose at SNL CA were tritium and uranium (ORAUT 2007a, pg. 43). Routine bioassay for radionuclides other than tritium and uranium are lacking (ORAUT 2007a, pg. 43).

> *The primary detection method for intakes of ^{3}H at all SNL facilities has been urine bioassay (Potter ca. 1997). There is no evidence that bioassay samples were analyzed for any radionuclides except H-3 and natural uranium (U-nat), or that other types of bioassay i.e. fecal analyses or in vivo counting, were employed at SNL/CA. The H-3 bioassay was limited to TRL experimenters and staff. The*

> *uranium bioassay was performed on individuals involved in machining DU as well as others involved with handling uranium powders or those in areas where air concentrations potentially exceeded 10% of the air concentration guidelines (Wright 1979).*

This begs the question of whether the employees at the SNL CA were adequately monitored for potential exposure to other radionuclides used at the site.

Documentation has been obtained by SC&A that as many as 24 different radionuclides were used at the SNL CA facility. This documentation was provided to the California Department of Health Services (CDHS) by SNL CA through the Albuquerque office of the Department of Energy (DOE-AL) in response to the CDHS request to DOE. The memorandum states (Ormond III 1989):

> *From the mid 50's to present, Sandia has used the following radionuclides within California. These materials have been used at the Sandia National Laboratories, at Livermore. Considerable effort would be required to track usage.*
>
> *Radionuclides:*

H-3	*Kr-85*	*Tl-204*	*Co-60*	*U-238*
C-14	*Tc-99*	*Tb-161*	*Pu-239*	*U-235*
Tl-204	*Ba-133*	*Pu-238*	*Fe-55*	*Ir-192*
Pm-147	*Cd-109*	*RaD+E*	*Ni-63*	*Ir-192*
Sr-90	*Cs-137*	*Co-57*	*Ru-106*	*Cf-252*
Am-241.				

However, the CDHS requested a list of each DOE (or predecessor) use of radioactive material within California from 1940 to the present (Themelis 1989); hence, the supplied list of the radionuclides used at SNL Livermore. These types of radionuclides range from long-life alpha emitters to beta emitters and gamma emitters, presenting various potential exposure concerns. Stanford (1989) noted that identifying the quantities of these radionuclides used would be classified. Thus, the extent of the use of these various radionuclides and the quantities has not been obtained by SC&A.

Thorium, Pu-239, and MFPs are identified as being in "Storage Facilities" in Table 2-1, "Area" information and parameters. Thorium is identified in the profile several times as being used at the site and is not discussed in the internal dose section. Section 2.3, "Site Activities," states:

> *There were some thorium metal parts used on test systems as well (Wright 2006).*

Section 4.4.1, "Locations of Concern," states:

> *An aerial survey of LLNL and SNL/CA, conducted in 1975 (Tipton 1977), found gamma-emitting radioactivity in excess of background levels in the vicinity of Building 9143 (the Radiography Building at the time) and to a much lesser extent,*

> *in the vicinity of a waste holding area known to contain DU and thorium (Building 9122), and a material storage vault known to contain DU, thorium, and small amounts of shielded ^{60}Co and ^{133}Ba, and ^{235}U (Building 921, incorrectly referred to as B-291 in the Tipton 1977 report).*

Attachment A of the site profile, "Summary of Activities at Site Buildings," lists natural thorium as being contained in Building 927, Radiological Material Storage. Natural thorium relatively quickly becomes a concentrated generator of thoron (Rn-220) gas after it is produced from the extraction process of thorium ore milling, because the radium daughter/decay product (Ra-224) that produces the thoron comes into activity equilibrium with the Th-228 in the natural thorium within a few weeks. Therefore, NIOSH should investigate the possibility of internal doses to claimants from thoron at the site.

In 1978, 75% of the total SNL CA waste was uranium-contaminated waste (primarily DU). Classified radioactive waste was accumulated and shipped offsite when sufficient quantities had accumulated (Jones 1978).

> *Mixed fission products and uranium contaminated wastes account for about 99 percent of the total SLL wastes. The fission product waste is generated from weapons tests at NTS and the uranium waste comes from research and development at the site.*

Futhermore,

> *Materials from NTS are generally returned to SLL, Bldg. 913 and 921 designed as number 16 and 4 respectively in Figure 2* (Lovell 1974).

This would indicate that there were activities involving fission products at the site.

Radiation dosimeters are required when working with weapon systems (1) for any activity that requires personnel to spend more than 16 hours per calendar quarter at distances closer than 1 meter to weapons with >1 kilogram of DU or thorium, and (2) for any activity that requires personnel to spend more than 4 hours per calendar quarter at distances closer than 1 meter to weapons with >1 kilogram plutonium (Russell 1995).

There is indication that radionuclides other than tritium and uranium were handled at SNL CA. Details on the quantities, forms, and handling conditions deserve further consideration in the site profile. With the presence of these radionuclides, and the absence of bioassay data for radionuclides other than tritium and uranium, consideration needs to be given to missed dose from exposure to these radionuclides due to the relative position of the dosimeter to the radiation source. Furthermore, an investigation into radionuclides handled as a part of classified activities is warranted to ensure that potential exposure situations to other radionuclides did not exist.

Plutonium-239 and MFPs were handled in at least trace amounts, according to the site profile (Table 2-1), but no discussion is given in the internal dose section to account for any potential exposures and intakes of these. Since bioassay was not performed to detect intakes of thorium, Pu-239 or MFPs and these radionuclides were handled or at least stored at the site, NIOSH must confirm and explain in more detail that there was no potential for occupational intakes of these other radionuclides before assuming intakes did not occur.

Offsite Internal Exposure

Sewell (1959) specifically authorized the thorium hydrodynamics program at Site 300 in 1959. This indicates that SNL CA workers located at, or visiting, Site 300 of LLNL were potentially exposed to thorium in addition to the DU and tritium mentioned in the SNL CA site profile. Thorium bioassay data is unavailable for Sandia workers potentially exposed to thorium at Site 300 or in the thorium machining area.

As previously mentioned, Sandia personnel were involved in testing at PPG, NTS, and other areas. In addition, post-shot materials were returned to the site following detonations for testing and evaluation. These activities exposed them to plutonium, uranium, tritium, MFPs, and MAPs. The conditions for exposure during weapons testing were unique, with a wide variety of radionuclides present in the source term. Bioassay monitoring through the NTS and PPG monitoring programs only included gross gamma and beta activity, and fission and activation product concentrations varied with the time of exposure after detonation. The available monitoring records, process descriptions, and source term data are inadequate to support internal dose reconstruction. Sponsoring laboratory personnel worked in conjunction with NTS and PPG workers as previously explained, some being assigned to NTS and PPG for extended periods of time. Equipment and materials returned to SNL CA from weapons tests may have been contamination with plutonium, uranium, tritium, MFPs and MAPs. Although there is mention that items were returned from the test sites, there is a general lack of detail on what was sent to SNL CA and how long after detonation this occurred. There is no method to identify the radionuclides present in the exposure source term.

The adequacy of monitoring data at DOE weapons testing sites is not a unique concern, but data adequacy issues are associated with monitoring data at other sites visited, including LLNL, RFP, the Mound Plant, LANL, IAAP, and the Y-12 Plant. The internal monitoring program for tritium and uranium at SNL CA would not encompass potential exposure for these other radionuclides at visited sites.

Internal monitoring data identified for offsite activities consisted of tritium for some years at LLNL; however, the internal exposure potentials were not limited to tritium, but included plutonium, thorium, MFPs, MAPs, and other radionuclides. The policy for monitoring visitors throughout the complex is not clear from site to site, and data for visitors is often difficult to locate, since it is not always stored in the same location as permanent employee records. Some analysis of the completeness of data for Sandia travelers is necessary, as the data do not appear to be available through SNL NM or through many of the host sites.

The SNL CA internal monitoring programs does not provide coverage of potential exposures to radionuclides encountered at other sites, including plutonium, thorium, MFPs, MAPs, and other radionuclides. Coverage of tritium and uranium exposure by the onsite internal monitoring program would depend on the solubility and date of sampling relative to date of exposure. This data may or may not be useable, depending on the individual situation under consideration. In the case of offsite exposure, the assumption of DU is not always appropriate. Bounding exposures for offsite visits is very difficult, considering the visitor or temporary status of Sandia personnel at these sites, the difficulties in locating visitor bioassay monitoring records, and the lack of information available for offsite exposures within the Sandia monitoring records system. Quantifying these exposures is critical to the assessment of dose to many Sandia workers, as internal exposure was more probable from offsite activities for those who frequented other DOE complex sites.

3.4 FINDING 4: THE TBD HAS NOT ADEQUATELY CHARACTERIZED THE EXTERNAL MONITORING PROGRAM IMPLEMENTED AT SNL CA

There is limited information on the dosimetry systems implemented at SNL CA prior to 1989, including a lack of information on the MDLs, exchange frequency, dosimetry calibration, dose calculation algorithms, and uncertainties and bias associated with each dosimetry technology. There is also indication that some dosimetry systems implemented by SNL CA lacked the ability to discriminate between beta, photon, and neutron exposures. Assumptions are made regarding the types and energies of external radiation hazards without consideration of actual field measurements. Finally, there are uncertainties associated with the assignment of missed dose, since MDLs and exchange frequency were estimated.

Inadequacies in External Dosimetry System

SNL CA has utilized several outside laboratories and contractors in the administration of its external dosimetry system, including LLNL (1956–1959), Radiation Detection Company (RDC; 1959–1971), Radiological and Environmental Services Laboratory (RESL; 1972–1988), and SNL NM (1989–present). SNL CA workers wore a two2-element beta/photon film badge with NTA film from 1956 to 1971. Sometime between 1966 and 1972, the site switched to a 2-element TLD. It appears that NTA film remained in use through 1971 for monitoring neutron exposures, but it is not clear how RESL measured neutron exposures from 1972–1982. An Eberline 3-element TLD was used for beta, photon, and neutron detection from 1982 to 1988. With the transition of the program to SNL NM in 1989, a multi-element TLD was implemented. The first DOELAP-accredited dosimetry system, a multi-element TLD, was implemented in 1991 and continues to be in use (ORAUT 2007a).

Radiological activities are associated with the Weapons Laboratory Facility Complex (Buildings 910, 912, 913, 914, 916, and 918), Radiography (Building 923), Micro and Nano Technologies Laboratories (Buildings 941, 942, and 943), the Explosives and Environmental Testing Complex (Buildings 955, 956, 966, 972, 974, 976, 977, 978, 979, 981, and 983), and the Storage Facilities (Buildings 921, 927, 961, and 982). Table 6-4 of the site profile indicates that neutron exposures are limited to Radiography Building 923 and testing/repair of neutron and x-ray detectors (neutron and x-ray generators) in the Weapons Laboratory Facility Complex. Indications of "minor fast neutron exposures in Building 912, Building 913, and the trailers adjacent to Building 914" (Rhodes 1960) appear to be consistent with this analysis. Rhodes (1958) characterized x-ray sources at SNL CA as ranging from 50–250 kVP. Alpha, beta, and gamma sources have been identified in SNL CA records, including Cobalt-60, Cesium-137, Iridium-192, Thulium-170, radium, Strontium-90, uranium, and related project metals. External radiological hazards resulted from handling uranium and thorium. The presence of other radionuclides, such as Kr-85, EU, and MFPs, also contributed to external exposure at SNL CA (Wright 2006, Jones 1978, Russell 1995).

Table 6-4 of the site profile lists radiation energies and percentages for beta, photon, and neutron radiation by site location and process activity. The distribution of beta, photon, and neutrons into energy categories is based primarily on estimates by site personnel (ORAUT 2007a). These values should be substantiated based on documented field measurements, some of which may be classified in nature. The site profile does not appear to consider external dose sources other than radiography sources, neutron/x-ray generators, and DU, although several isotopes have been identified in SNL CA records (refer to the preceding paragraph). It is not readily apparent that all of these activities and sources have been considered in Table 6-4 or in Attachment A: "Summary of Activities at Site Buildings." Further assessment of field documentation is necessary to assure that the external radiation sources at SNL CA have been adequately characterized.

Issues have been raised regarding the ability of SNL CA dosimeters to adequately distinguish radiation exposures from the source term to which workers were exposed. SNL CA used a 2-chip, single-filter dosimeter from 1972 to 1982. The badge was incapable of distinguishing between types of penetrating (deep dose) radiations and non-penetrating (skin or shallow dose) radiations (Wright 1981, Lovell 1983). The site profile states:

> *As mentioned previously, the 2-chip, single filter TLD dosimeters in use from 1972 to 1982 apparently could not directly measure each of the various dose quantities reported in the record for this period. No definitive information has been located with respect to adjustments to recorded dose, nor has any information been found regarding dose calculation algorithms, system MDLs, or uncertainty/bias doses during this period.* (ORAUT 2007a, pp. 61–62)

Lovell (1983) outlines the deficiencies of the dosimeter related to its lack of energy discrimination.

1. *Lack of Energy Discrimination*

   a. *TLD cover is 30 mg/cm^2 (density X thickness)*
      1) *skin sensitive layer 7 mg/cm^2*
      2) *critical organs 1000 mg/cm^2*

   b. *Insensitive to beta particles between 50 keV and 200 keV. Beta particles >70 keV can reach the radiosensitive layer of the skin (7 mg/cm^2).*

   c. *Does not distinguish between beta particles/low energy X-rays and gamma rays, and high energy X-rays/gamma-rays.*

> d. *SNL CA is forced to add all exposures to low energy X-rays and beta particles – to whole body penetrating dose, unless the exposure circumstances are known.*

The dosimetry records for the period include beta, photon, and neutron dose results, as acknowledged in the site profile. Lovell (1983) does not discuss the impact of this dosimeter on neutron uncertainties and biases.

For the period of 1972 to 1988, the dosimetry services were outsourced to RESL in Idaho Falls, Idaho (Wright 1993, Wallace 1988, Ormond 1986). The site profile indicates the following:

> *Currently, no information is available regarding calibration of TLD badges used by SNL/CA between 1971 and 1988 (the period in which RESL performed dosimetry services).* (ORAUT 2007a, pg. 59)

In addition to problems with the 2-chip TLD used at SNL CA, the site profile indicates incomplete or inadequate information for the 3-element Eberline TLD badges:

> *Like the earlier period in which 2-chip TLD's were used at SNL/CA and processed by RESL in Idaho, there is no documentation regarding dose calculation algorithms, adjustments to recorded dose, or uncertainty/bias for the 3-element Eberline TLD badges used from 1982 to 1988.* (ORAUT 2007a, pg. 62)

As indicated in the site profile, there is a lack of information regarding the dosimetry program prior to 1989 (ORAUT 2007a, pg. 61). Furthermore, the site profile fails to identify the year of transition from the film badge to the TLD (ORAUT 2007a, pg. 57).

For a dosimeter to adequately determine the dose, the program must assess and account for several parameters, including the workplace radiation fields (e.g., types of radiation, exposure geometry, environmental conditions), the physical capabilities of the dosimeter (i.e., response to different types and energies of radiation), administrative practices used to calculate and record dose, calibration, and similarity of the calibration method to the conditions and sources of exposure encountered in the workplace. Without adequate documentation of how these factors were addressed, it is difficult to characterize the uncertainties associated with the doses of record. It may be necessary to apply dosimeter correction factors to account for inadequacies identified with dosimetry systems, but additional information is needed to support the development of appropriate correction factors.

Dosimetry uncertainties for SNL CA dosimeters presented in the site profile are based on bias and uncertainty estimates in the *Technical Basis Document for the Hanford Site – Occupational External Dosimetry* (ORAUT 2006c). The rationale in the site profile for using Hanford uncertainties is that "some general analogies can be drawn between Hanford and SNL/CA in terms of dosimetry technologies employed during various time periods of interest" (ORAUT 2007a, pg. 67). Given the numerous uncertainties related to SNL CA's dosimetry technology, calibration, processing, and recording practices, the selection and use of Hanford uncertainty values requires more explicit justification.

In summary, given the uncertainties in the dosimetry technology, calibration, dose calculation algorithms, adjustments to recorded dose, and uncertainty and bias factors, there is a need to conduct further research on radiological conditions and external dosimetry systems utilized at SNL CA prior to 1989. Since SNL CA used offsite dosimetry services, including LLNL (1956–1959), RDC (1959–1971), and RESL (1972–1988), some of the necessary information regarding dosimetry processing, design, and calibration may be obtainable from these vendors. Some information is available in the ORAUT *Idaho National Laboratory – Occupational External Dosimetry* TBD (ORAUT 2007c) on calibration techniques used at RESL and the laboratory uncertainties associated with these techniques. The characterization of radiation energies and relative percentages, estimated primarily by site personnel, should be validated based on actual field measurements. Justification should be provided regarding the use of surrogate data (i.e., Hanford uncertainty corrections). Finally, clear directions are needed to support consistent use of tables, data, adjustments, and corrections to ensure reliable and claimant-favorable dose reconstruction.

Missed Dose Determination

The lack of documentation on dosimeter MDLs for the period prior to 1989 has resulted in a necessity to estimate dosimetry MDLs based on dosimetry systems of contemporary technologies used at other AEC or DOE facilities during corresponding periods. These estimated MDLs were estimated based on the *Technical Basis Document for Oak Ridge National Laboratory – Occupational External Dose* (ORAUT 2004b), the *Lawrence Livermore National Laboratory – Occupational External Dose* (2005c), *Technical Basis Document for the Hanford Site – Occupational External Dosimetry* (ORAUT 2006c), and the *Summary Site Profile Document for Brookhaven National Laboratory* (2006d). The estimated maximum annual missed photon, beta, and neutron dose is presented in Table 6-6 (ORAUT 2007a, pg. 66). The use of surrogate data from other AEC and DOE sites requires the demonstration of equivalency between the field exposure conditions, dosimetry system, processing protocol, and recording practices used at SNL CA, and those sites from which surrogate data is used. While the SNL CA site profile indicates that the dosimetry system used at SNL CA was similar to contemporary technologies used at other sites, it does not provide a discussion justifying the equivalency between the SNL CA dosimetry system and those from the sites above.

Missed dose is based on estimates of dosimetry system MDLs and exchange frequencies of the dosimeters assigned to personnel. The site profile also raises uncertainties regarding exchange frequencies for dosimeters (ORAUT 2007a, pg. 55).

> *While not made explicitly clear in Section 8.4.1 of SNL's External Dosimetry Program Manual (Ward et. al., 1994), routine field dosimeter exchanges appear to occur on a monthly or quarterly basis, while nonroutine exchanges occur on a bi-weekly basis (for special radiation work cases, exchange periods may vary).*

Table 6-6 assumes a monthly maximum exchange frequency, with exchange frequencies for TLD systems ranging from quarterly to annually. The data provided to NIOSH from SNL CA included minimal cycle-specific data. In some cases, only cumulative exposure summaries are provided, which cover years of monitoring. This, combined with the lack of dosimetry program history prior to 1989, makes establishing an exchange frequency difficult. Although this information may not be readily available through SNL CA, much of this information is likely retrievable through the dosimetry vendor employed by SNL CA.

In the absence of MDL and exchange frequency values available for SNL CA, the site profile has relied on estimates. These estimates were derived from surrogate information from other AEC and DOE sites. Given the scope of activities and extent of the dosimetry programs at ORNL, LLNL, Hanford, and BNL compared to those at SNL CA, discussion of data equivalency should be provided in the TBD to demonstrate assumptions from these other DOE sites are appropriate for SNL CA. This is particularly prudent, given discussions regarding use of surrogate data from other sites at the Advisory Board meeting in February 2010 (ABRWH 2010). Further investigation into the protocols for dosimetry exchange should be conducted, since this is a critical factor to the assignment of missed dose.

3.5 FINDING 5: THE SNL CA TBD HAS NOT ADEQUATELY CHARACTERIZED NEUTRON EXPOSURES AND HAS NOT ACCOUNTED FOR THE LACK OF RESPONSE OF NTA FILM TO LOW-ENERGY NEUTRONS

The site profile does not specifically address the subject of NTA film threshold. The threshold energy of NTA film (0.5–1.0 MeV) and the amount of dose not registered because of this threshold is important in neutron dosimetry. NTA film decreases in response starting at neutron energies below 1 MeV, and is almost completely insensitive to neutrons below 0.5 MeV (ORAUT 2005d, pg. 27); therefore, radiation fields containing an appreciable percentage of the total dose equivalent due to neutrons with energies below 1 MeV must be evaluated carefully, with attention given to the dose missed due to this threshold effect. NTA tracks fade more rapidly with time as the interacting neutron energy decreases, resulting in more missed neutron dose. Section 6.4.2 indicates NTA film was used through 1971 to monitor for neutron exposure. Table 6-4, *Selection of Radiation Energies and Percentages*, provides the exposure energy spectra, including neutron energy spectra less than 1 MeV (ORAUT 2007a, pg. 65). According to Lovell (1983), SNL CA personnel were potentially exposed to fission spectrum neutrons up to 14 MeV during radiography work, with some operations involving accelerators. It is reasonable to assume that, regardless of the initial neutron energy produced from a neutron source or neutron generator, the spectrum to which workers were exposed would contain neutron energies less than 1 MeV. This is consistent with information from other DOE sites with similar operations.

RDC issued an informational bulletin on *The R-D Neutron Film Badge Service* (RDC, no date) describing the R-D Universal Film Badge, which contained both beta-gamma film and an Eastman-type NTA track plate film. The NTA track plates were calibrated with a polonium-beryllium source. High-energy neutrons were determined by the number of tracks in 25 fields. Thermal neutrons were determined by increased density under the cadmium filter of the R-D beta-gamma film. RDC (no date) went on to describe that NTA emulsion is subject to latent image fading, recommending bi-weekly or monthly exchange. With this exchange frequency, RDC (no date) indicated that the latent image fading would be low "unless low neutron energies were encountered."

While the site profile considers a correction factor for conversion from NCRP Report 38, Neutron Quality Factors, to ICRP Publication 60, Radiation Weighting Factors (ORAUT 2006a), it does not consider the lack of or reduced response of NTA film to neutron energies less than 1 MeV. The lack of details on this issue may lead to a lack of understanding on the part of the dose reconstructor regarding how to address low-energy neutrons in dose reconstruction. An appropriate correction factor or alternate methodology should be included in the site profile to compensate for the under-response of NTA film to low-energy neutrons. The recommended approach for adjustment of neutron dose is also inconsistent with the approach presented in other site profiles where low-energy neutrons were of concern.

3.6 FINDING 6: LACK OF CONSIDERATION OF SPECIAL TRITIUM COMPOUNDS

The site profile discusses the use of tritium at the TRL from 1976 through 1992 when operations were terminated. Clean-up activities were conducted from January 1992 to December 1995 (ORAUT 2007a, pg. 42). The site profile focuses on tritium exposures at the TRL, indicating that "tritium exposure primarily occurred at TRL" (ORAUT 2007a, pg. 43). Discussion on uranium alloy machining mention the use of uranium tritide beds in Building 968 (ORAUT 2007a, pg. 43). Attachment A, "Summary of Activities at Site Buildings," lists tritium as a nuclide of concern for Buildings 913, 961, 969, 974, and ESA in addition to the TRL facility (ORAUT 2007a, pg. 84–86). Information on tritium usage at SNL CA has concentrated on the TRL, and little information is provided on tritium-related activities at other areas of the site, including bioassay requirements. The site profile has not adequately characterized the potential for exposure to special tritium compounds (STCs), either from intentional R&D activities or from production of these compounds as a byproduct of diffusion, absorption, and reactivity of elemental tritium and HTO with structural material. Formation of byproduct STCs becomes important when conducting intrusive activities on tritium handling systems or during decontamination and decommissioning (D&D) of a tritium facility.

SNL CA involvement with design and development of neutron generators and tritium reservoirs pre-dated the existence of the TRL. Sandia personnel were responsible for developing innovative technologies for tritium reservoirs and associated gas valves. In 1960, SNL began designing reservoirs capable of maintaining their charge for longer periods. In about 1968, SNL CA built a tritium research laboratory to develop ways to handle, store, and inject the rare gas into weapon components. Researchers learned they needed exotic metal alloys that could resist embrittlement caused by helium, tritium's decay product (Maroncelli and Karpin 2002). The operational safety requirements for the TRL describe tasks conducted in the facility as follows (Putz et al. 1988):

> *The research and development tasks conducted at the TRL are dynamic. The processes and process variables associated with these studies are in a continuous state of change as the investigation requirements change.*

Examples of R&D activities conducted at SNL CA clearly involved charging of metal and metal alloys with tritium, use of tritium storage beds, diffusion studies, and evaluation of tritium containers.

- Tritium was introduced at elevated temperatures into titanium alumide samples by use of a charging apparatus. This allowed for autoradiography to observe the microstructural distribution of hydrogen in alloys (Perra et al. 1988).

- Tritium gas was introduced into titanium alloy fracture mechanics specimens to observe hydrogen diffusion behavior during mechanical stressing (Perra et al. 1987).

- Studies were conducted on tritium solubility in metals as a function of temperature and pressure. Experiments included investigation of low solubility metals, such as copper, gold, aluminum, and beryllium (Stulen et al. 1987).

- TRL conducted experiments with tritium-labeled liquids used in corrosive and stress corrosion cracking studies (Putz et al. 1987).

- SNL CA established a program associated with loading, monitoring and sampling of Tritide Studies Program (TSP) storage units. The units were tritium-charged in the TRL assay station and/or the high-pressure station, and periodically sampled (Ormond 1988).

- Uranium and palladium beds were used to store tritium as uranium tritide and palladium tritide, respectively, and to provide a source of tritium for TRL research and operations (Wall 1994a, Wall 1994b).

- Experiments with palladium samples previous tritided were conducted in Building 913 (Hruby 1990).

Field RadCon staff, in interviews conducted with SC&A, indicated that tritium (gas and water) will eventually permeate through rubber gloves, seals, gloveboxes, etc. As a result, there was tritium contamination in accessible areas (see Attachment 1). In addition to production and R&D activities, STCs are formed as byproduct materials from prolonged exposure to materials (DOE 2008).

> *DOE facilities have used a wide variety of metals (e.g., Ti, Zr, U, and Hf) in tritium research, purification, and storage creating an equally wide variety of materials referred to as "metal tritides." Metal oxides (e.g., rust), siliceous materials (environmental dust), and carbonaceous materials (e.g., polymers or environmental dust) can also become tritium contaminated and exhibit particulate properties. Tritium may also react with organic material, resulting in the formation of organically-bound tritium (OBT). The main types of OBT encountered in the DOE complex are solvents, oils, and solid particulates (e.g., plastics, nylon, and organic dust forms). OBT can be particulate or non-particulate in nature.*

Furthermore,

> *Tritiated metals, metal oxides, dust, and oil can occur in nearly any tritium area. Any tritium contamination collected on a swipe survey or a particulate filter should be viewed as a potential combination of these.* (DOE 2006)

And

> *Any area where tritium is used, handled or stored may result in the formation of metal tritides.* (Pantex 2004)

Other significant sources of metal tritides are areas where neutron generator residues (titanium tritides) may be present (Pantex 2004). Furthermore, involvement in offsite assembly and disassembly operations had the potential to result in exposure to STCs not specifically handled at SNL CA.

The extent of diffusion, absorption, and reactivity is dependent on factors including pressure, temperature, and tritium concentration. Sandia experiments involved a wide range of temperatures and pressures depending on the specific study.

The potential for exposure to compounds other than elemental tritium and HTO occurred during the removal of tritium beds from gloveboxes, handling of tritium in unenclosed systems (allowed for small quantities), assembly and storage areas, waste handling, system maintenance and repair, and during D&D of tritium facilities. While a preponderance of tritium activities were conducted in gloveboxes, there were situations where lapse of control occurred. In statements provided to NIOSH by Tri-Valley Cares (TVC 2007) on the site profile, two examples of lapse of control were provided.

> *A tritium leak occurred at Sandia Livermore, when a Teflon seat in a pressure regulator valve on a deuterium/tritium bottle cracked after exposure to the 800-psi gas mixture. Operations personnel didn't realize that the pressure regulator contained Teflon; therefore, they took no special precautions.*

And,

> *Four workers involved with dismantling the Vacuum Effluent Recovery System (VERS) and Gas Purification System (GPS) were involved in an incident with tritium contaminated hardware. The VERS typically collects effluent from gloveboxes and the exhaust from vacuum pumps. The oil from the vacuum pumps normally condenses in its exhaust manifolds. In BUILDING 968 Room 115A, workers were cutting up contaminated copper and steel pipe with Jaw of Life units. They encountered an unknown oil pocket which spilled on one worker's garment and shoes. Work was suspended, the oil spill was cleaned up and the room evacuated. Bio-assay and perspiration swipes (sample) were immediately taken which showed elevated radioactive levels in the body.*

The diffusion is much more pronounced in systems where the tritium is under high pressure, as is the case in some programs. These reactions can lead to formation of tritium oxide or "rust," which is very insoluble, with penetration into the metal matrix. Thus, stainless steel gloveboxes, gloves, gaskets, and other components in production, disassembly of weapon systems, or research facilities can become contaminated with SMTs or OBTs. The extent of this diffusion and reactivity is significantly increased with increased pressures and temperatures.

The issue of diffusion, absorption, and reactivity of tritium has been discussed with site experts at SRS, SNL, LANL, the Pantex Plant, and the Mound Plant.

Tritium Handling and Safe Storage (DOE 2008) states:

> *Tritium has a high coefficient of diffusion. It readily diffuses through porous substances such as rubber and can also diffuse through metals.*
>
> *Tritium gas permeates through most materials, that is, it travels through them by way of spaces or interstices in them. The rate depends upon the material and its thickness.*
>
> *Recently, sensitivity to STC contamination has been increased as a result of recent DOE activities involving decontamination and decommissioning* [D&D] *of older facilities. These activities may compromise the effectiveness of the design features and allow releases of STC contamination to the surrounding areas. Such releases may cause exposures to individuals in the area and releases of STCs to the environment both on- and off-site.*

It should be pointed out that design features implemented in later tritium facilities did not always exist in earlier facilities, or in areas where STCs were generated byproducts.

The site profile discusses the protocol and frequency of bioassay sampling conducted for tritium at SNL CA. The criteria for placing individuals on a routine tritium bioassay program are defined in the *Health Physics Programs and Implementing Procedures* (SNL CA 1990).

> *Individuals who work with tritium handling systems, equipment, materials or samples contaminated above the "Control Area" limit of 10,000 dpm/100 cm^2 or who have been in areas where a low level alarm has occurred or Derived Air Concentrations exceeded, will submit urine samples as described below. Casual visitors or tour groups are expected to remain with escorts who are familiar with the bioassay requirements. Any person who has visited another tritium facility within the past 30 days should submit to baseline urine sample. DOE personnel, and contractors from other sites with tritium facilities, are expected to submit a baseline and followup sample. All visitors to the TRL are required to log-in at the entrance at least once per visit period in order to provide their employer with bioassay results.*

Personnel, contractors, or frequent users of the TRL were required to submit urine samples either weekly or at the end of a visit/job, whichever is shorter, as a minimum frequency. A database was used to calculate the average tritium concentration in urine for each person for the quarter and the number of samples collected. Radiation doses are normally calculated assuming chronic exposures unless significant acute exposures are found. In this case, the quarterly dose was the sum of chronic and acute doses. If the quarterly dose exceeded 10 mrem, the tritium dose will be added to the individual's quarterly whole-body dose equivalent. Dose calculations assumed tritiated water with a default biological half-life of 10 days. Personnel were removed from tritium work when their urine concentration reached the reference level of 10 μCi/l until a subsequent urinalysis fell below the reference level (SNL CA 1990). These calculations assume an intake of tritiated water.

In Table 5-9, the solubility shown for tritium only includes tritiated water, which is not inclusive of all forms of tritium at SNL CA. The site profile (ORAUT 2007a, pg. 43) mentions the Uranium Tritide Bed installed at the TRL in 1991, which presented a potential for exposure to uranium tritide. Uranium tritide is assigned a solubility of Type S followed by the statement, "no data to show tritide is more soluble than metal" (ORAUT 2007a, pg. 52). The assumption of Type S for uranium tritide is in conflict with DOE (2008), which identifies uranium tritide as a soluble particulate tritium compound. Furthermore, the assumption of Type S is inconsistent with the Type F class assumed for the Mound Plant. For intermediately soluble or insoluble tritium compounds, the effective dose equivalent and the lung dose equivalent will be underestimated if urine bioassay data are interpreted assuming an intake of tritiated water. The ability to detect tritium in urine relies on the disassociation of the tritium compound, and in some cases, these compounds are very stable.

The solubility of OBT compounds is dependent on the specific compound, and can range from more soluble than HTO to an order of magnitude or more less soluble. Taylor (1986) states:

> *It is concluded that although the ICRP OBT model may underestimate doses for specific compounds by up to an order of magnitude, it can still be applied with caution for prospective radiological protection purposes, but it should not be applied for the interpretation of bioassay data.*

The site profile considers only HTO in the calculation of tritium dose at SNL CA. Special tritium compounds (STCs) formed intentionally or as byproducts of handling large quantities of tritium gas and tritiated water are not adequately considered by the site profile. Solubilities and biokinetic distribution of STCs vary from that of HTO and must be considered in the assessment of tritium dose. For tritium, it is important that the dose reconstructor chooses claimant-favorable forms of tritium for the dose estimation if there is a lack of process knowledge about the form that may have been involved with exposures. Doses from exposure to STCs can be underestimated by orders of magnitude if dose is calculated based on an HTO uptake in place of an STC uptake. Given the existence of STCs at SNL CA, further consideration needs to be given to potential exposures and resulting doses from these STCs. Furthermore, assignment of Type S solubility for uranium tritide is inconsistent with the available DOE documentation and assumptions made for dose reconstruction at other sites handling uranium tritide.

Currently proposed approaches developed by NIOSH for estimating dose from STCs rely on the use of urine bioassay results in concentration (e.g., µCi/L). In the absence of bioassay data, the site profile should discuss in detail how dose will be estimated for STCs, particularly those compounds not readily disassociated to soluble compounds in the body.

3.7 FINDING 7: ASSUMPTIONS FOR URANIUM DOSE ASSESSMENT ARE NOT CLAIMANT FAVORABLE

During the period of the first uranium bioassay (prior to 1968, specific date not identified by NIOSH) to 1990, fluorometry was used to determine uranium mass concentration (µg/l) in urine. The site profile indicates that from 1990–1993, samples were analyzed by a contractor laboratory, CEP, which was subsequently found to be providing suspect bioassay results. NIOSH determined that these recorded results should not be used (ORAUT 2007a, pg. 48). From 1993 to the present, NIOSH does not confirm the method of analysis, but suggests it was probably done using ICP-MS.

Uranium bioassay was conducted for SNL CA workers who met the following criteria (SNL CA 1990):

> *The technical basis for uranium bioassay sampling is based upon the potential for uptake by the various modes, such as inhalation, ingestion, or skin absorption. Soluble forms of uranium are infrequently handled at SNL Livermore, and usually in small quantities. Air sampling may be inadequate to identify uptakes resulting from skin absorption, particularly if the material is handled in a chemical fume hood. Personnel will be started on a minimum bioassay program if they meet any of the following criteria:*
>
> 1. *When air sampling of the workplace demonstrates that uranium air concentrations may reach or exceed 10% of the Derived Air Concentration: 2 E-11 µCi/ml.*
> 2. *Wet or dry machining or other operations where air sampling may not be indicative of uptake.*
> 3. *The handling of soluble uranium compounds, where airborne measurements may not be indicative of uptake, such as by skin absorption.*
> 4. *Routine work in an area posted as a "Contaminated Area" regardless of the air sample results.*

For Class D uranium compounds, routine samples were collected monthly, and for Class W or Y uranium compounds, samples were collected semi-annually. Non-routine uranium bioassay samples were submitted under the following conditions (SNL CA 1990):

> *The technical basis for nonroutine bioassay is not based upon measured or potential air concentrations, but rather accidental or suspected exposure when air sampling data is not available. A bioassay sample will be collected 48 hours post exposure for the following incidents:*
>
> 1. *Skin contact with a soluble form of uranium.*
>
> 2. *Exposure to a uranium fire, or an event resulting in contaminated nasal wipes.*
>
> 3. *A cut or lesion that may have injected uranium or it's compounds under the skin. Wound counts may not be sensitive enough to detect depleted uranium in a deep cut.*
>
> 4. *Baseline samples may be collected for personnel starting work with uranium.*

An investigation level set for uranium was 0.3 Allowable Limit on Intake (ALI)/N, where N is the number of monitoring periods, or 2.25E-2 g (insoluble uranium) and 1.2E-2 g (soluble uranium). The uranium dose is included in the effective dose if the concentration is equal to or greater than 0.1 ALI/N. An assumption of 1 micron AMAD is assumed for dose assessment purposes (SNL CA 1990).

Detection Limits

The uranium bioassay detection limits recommended for 1973–1987 appear to be too low for analysis by fluorometry. Uranium bioassay samples were forwarded to SNL NM for processing. In Section 5.9, "Summary Tables," Table 5-8, "Detection limits for total uranium bioassay," NIOSH identifies the minimum detectable activity (MDA) for uranium bioassay performed by fluorometry between 1973–1986 to be 1.1 micrograms per liter (µg/l), during 1975 to be 0.7 µg/l, and for 1986–1987 to be 3 µg/l. The health physics program and implementing procedures state (SNL CA 1990):

> *The measurement technique currently used by SNL Albuquerque is flourimetry of urine samples. SNL Albuquerque reports a MDL of 1–3 µg/L. Most of the uranium handled at SNL Livermore is depleted uranium making radioanalytical measurements difficult.*

Prior to 1973, the fluorometry bioassay MDA for uranium was identified to be 5 µg/L (which has been the industry standard MDA for this method), from 1987–1990 to be 10 µg/L, from 1991–1992 to be 12 µg/L (analyses by CEP determined to be invalid), and from 1993–present analyzed by ICP-MS (a much more sensitive method than fluorometry) to be 0.1 µg/L. The use of these significantly lower MDAs (than 5 µg/L) during the period from 1973–1987 is suspect, because it is questionable that the laboratory that performed these analyses could achieve a lower MDA than 5 µg/L. This "industry standard" MDA of 5 µg/L was identified in the site profiles by NIOSH to be in use at Portsmouth from 1954–1995 (ORAUT 2004a), Paducah from 1952–1998

(ORAUT 2007d), and Oak Ridge K-25 (ORAUT 2006b) from 1958–1989, which are sites that handled uranium in all forms of enrichment including DU. These questionably unusual and low MDAs that NIOSH plans to use for 1973–1987 will lead to significantly lower missed dose (minimum detectable dose) estimates than the use of 5 µg/L as the MDA.

Controls for Environmental Pollution (CEP)

Uranium bioassay samples from SNL CA were sent to SNL NM for analysis either in-house or by a contracted laboratory (Potter 1994). SNL NM, to which SNL CA samples were sent, contracted with CEP for bioassay services starting in February 1992 (Friedman 1998). The SNL NM site profile indicates that services continued through April 1994 (ORAUT 2007b). CEP had come under suspicion of data falsification in 1994 after bioassay data provided to Sandia were found to be questionable. SNL identified problems with the analyses performed by CEP (Ball et al. 1995) and eventually invalidated the uranium bioassay results received from CEP. This event calls into question the reliability of CEP's analytical services for Sandia, and thus SNL CA, who relied on Sandia to process their non-tritium bioassay samples. Table 5-2, "Preliminary time line uranium in urine analysis," specifies CEP as the source of bioassay analysis from 1990–1993 (ORAUT 2007a, pg. 48); however, the SNL NM site profile indicates the contract with CEP was from 1992 to 1994. This raises some question regarding the adequacy of data from 1990 to 1994. Bioassay data for this time period from other sources has not been located to date. The site profile identifies that uranium bioassay results from this period are not to be used; however, it does not give instruction to the dose reconstructor on how to assess uranium intakes and doses that could have occurred during this period for the staff that gave bioassay samples (these staff were identified by NIOSH to be at higher risk of exposure, according to the SNL CA monitoring policy). Furthermore, these data are not suitable for use in a coworker model. The complete lack of bioassay data places a reliance on the air sampling data conducted at SNL CA and its representativeness of worker exposure. This issue is discussed later in this report.

Solubility Assumptions

Table 5-9, "Solubility type, fraction activity and particle size," shows DU is likely in Type S solubility form; however, if it has not been highly oxidized, it may contain a significant fraction of Type M form, which would lead to different calculated internal doses to organs, depending on the organ of concern. Industrial uranium oxides are often mixtures of relatively soluble and insoluble fractions, with variability strongly influenced by process history (Edison 1994). NIOSH should further investigate the solubility of the DU handled at the site or recommend that more soluble forms, with a component of Type M, must also be considered if these assumptions increase the assessed dose to organs under consideration for the claimant. The site profile does not specify how the solubility issue will be addressed.

TRL handled uranium tritide in the form of powder in storage beds. This material is classified as metallic Type S material. The site profile goes on to further say that there is no data to show uranium tritide is more soluble than metal. The *Radiological Control Programs for Special Tritium Compounds* (DOE 2004) indicates that uranium tritide is a Type F compound. This should be corrected in the table and considered in former and current dose reconstructions.

Uranium Enrichment

In Section 5.3.2 of the site profile, the dose reconstructor is directed to assume a specific activity for DU when converting uranium bioassay mass concentrations to activity concentrations. The site profile further indicates that there is no information to demonstrate appreciable amounts of natural uranium (NU) or EU were used at SNL CA (ORAUT 2007a).

A "small" amount of U-235 (typically indicating highly EU) is identified as being at the site in Section 4.4.1, "Locations of Concern:"

> *An aerial survey of LLNL and SNL/CA, conducted in 1975 (Tipton 1977), found gamma-emitting radioactivity in excess of background levels in the vicinity of Building 9143 (the Radiography Building at the time) and to a much lesser extent, in the vicinity of a waste holding area known to contain DU and thorium (Building 9122), and a material storage vault known to contain DU, thorium, and small amounts of shielded ^{60}Co and ^{133}Ba, and ^{235}U (Building 921, incorrectly referred to as B-291 in the Tipton 1977 report).*

Furthermore, Section 5.2 states:

> *There is no evidence that urine bioassay samples were analyzed for any radionuclides except H-3 and natural uranium (U-nat)…*

NIOSH needs to clarify these apparently conflicting statements – "samples were analyzed for… natural uranium (U-nat)" and no "appreciable amounts of either natural or enriched uranium were used"… Was the uranium urine bioassay for U-nat or DU or total U, and was the analysis specifically for detecting DU intakes or was it possible that other enrichments of U could have been involved with intakes? This is critical when using mass concentration (µg/l) units in dose and intake calculations.

There appears to be some uncertainty regarding the handling of NU and EU at SNL CA. Little information has been identified regarding the form of the NU and EU, or the operations conducted with these materials. The range of enrichment is also unknown and requires further investigation.

If natural, low- and/or high-enrichment uranium was handled at site, this brings into question the appropriateness of assuming DU to convert mass concentrations to activity concentrations. The total uranium activity changes greatly with enrichment changes. Use of DU for dose estimates, when using bioassay data in units of mass concentration (µg/l), would cause an underestimation of dose for those exposed to normal or EU.

In summary, the uranium detection limits recommended in the site profile for the period 1973–1987 appear to be too low for analysis by fluorometry. The values proposed are well below the industry standard for this technique for this period of time. Uranium urinalysis samples collected from CEP (1990–1993 as defined in the site profile, and 1992–1994 as defined by SNL NM contract) is suspect and cannot be used for the determination of uranium dose or for inclusion in a coworker model. Solubility assumptions require update and correction based on currently available scientific data. The assumption for a mass conversion factor should be reflective of all enrichments of data handled at SNL CA, and not limited to DU. Defaulting to DU for conversion to activity when using bioassay data in units of mass concentration (µg/l) when the site handled NU and EU, would cause an underestimation of dose for those individuals exposed to normal or EU.

3.8 SECONDARY FINDINGS

Finding S1: Environmental Source Terms are Inadequately Characterized for SNL CA Workers Located or Participating in Activities at Site 300 of LLNL

When the AEC decided to established a Livermore branch of Sandia National Laboratory, 15 individuals were transferred from SNL NM to a temporary location at LLNL.

> *When I first came here in September 1955, our entire office consisted of space in Building 151 of UCRL. As we grew larger, we occupied additional space in Building 144. Later, we overflowed and maintained spaces in Buildings 136, 142, and 166*. (SNL CA, no date)

A review of the LLNL TBD indicates that both Building 151 and Site 300 handled radioactive materials potentially resulting in exposures to SNL CA workers.

Building No.	Building Activity	Radionuclide
151	Isotope Sciences, Environmental Services Laboratory	Ni-63, I-129, U-233, U-234, U-235, U-238, Np-237, U-236, Pu-236, Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, Pu-244, Am-241, Am-243, Cm-242, Cm-244, Cm-246, Cm-248, Cf-249
Site 300	Explosives Testing, Linear Accelerator, Radiography	H-3, N-13, Ar-41, U-234, U-235, U-238, O-15; H-3, C-14, Na-22, corrosion products, MFP, transuranics, U, Pu, Th

Sandia personnel continued to work at Site 300 throughout the operation of the SNL CA facility, including involvement in hydroshot testing. This is evident in the SNL CA claimant medical records, as working out at Site 300 required special medical clearance for at least some period of time.

The site profile is incomplete in its description of activities occurring at Site 300 and the potential radiological exposure conditions associated with these activities. Minimal dose reconstruction guidance is provided for environmental occupational dose, and it is clear from operational descriptions that guidelines allowed for experiments with NU, DU, natural thorium, tritium, and beryllium. Sewell (1959) specifically authorized the thorium hydrodynamics program at Site 300 in 1959. No method for assessment of environmental dose from alpha emitters and tritium is available prior to 1961 and 1972, respectively. Further evaluation of the implemented monitoring for this area and its adequacy for the radionuclides involved in tests is necessary.

Finding S2: No guidance is given to determine the environmental particulate radioactivity intakes for the period 1956–1960, and it is assumed that the alpha emitters U-234 and Pu-239 are the only contributors to dose from alpha emitters coming from the LLNL site releases from 1961–1970, which may not be claimant favorable in all cases

Section 4.3.3, "Annual Intake of Radioactivity" (ORAUT 2005b), does not provide intakes of particulate radionuclides for the years 1956–1960 apparently due to the fact that LLNL did not perform any site perimeter air sampling during this period. For all other years of operation, 1961–2004, LLNL south perimeter air sample data for particulates are used by NIOSH to estimate the maximum intakes of, and doses from, particulate radionuclides that SNL CA unmonitored personnel may have received. There is no explanation by NIOSH or guidance to the dose reconstructor for this period beyond restating that there is no data for 1956–1960 to estimate intakes of particulate radionuclides. NIOSH should investigate further the possibility that particulate radionuclides could have been inhaled by unmonitored staff during the period 1956–1960 and describe how these intakes will be calculated.

NIOSH identifies LLNL as the only source of particulate radionuclide exposure to unmonitored employees, and it is known that they handled several alpha emitters other than Pu-239 and uranium isotopes, which included thorium isotopes, Am-241, Cm-244, etc. In fact, NIOSH states, "In addition to ^{3}H, LLNL has processed and handled a number of radionuclides including uranium and transuranic elements, mixed fission products, and accelerator-produced isotopes." The assumption by NIOSH that gross alpha air sample results and therefore intakes of alpha emitters were only from U-234 (NIOSH assumes U-234 for all uranium isotope activity, because it has the largest dose factor of all uranium isotopes) or Pu-239 may not be accurate or claimant favorable. Since other alpha emitters (thorium isotopes, Am-241, Cm-244, etc.) could have been part of the released radionuclides, these should be considered as part of the intakes for dose assessment if the assumption of only U-234 and/or Pu-239 intakes do not provide higher doses to the organ of the claimant. Since NIOSH is basing the particulate radionuclide intakes by unmonitored employees on the nearest LLNL boundary air sampling data, NIOSH should consider alpha-emitting radionuclides other than Pu-239 and uranium isotopes, such as Th-232, as possibly detected in the air samples analyzed by gross alpha from 1961–1970.

Finding S3: NIOSH has assumed that there were no SNL CA-generated particulate radioactive airborne emissions of significance, which is somewhat unverifiable because of the lack of monitoring data.

Apparently, SNL CA essentially did not perform stack effluent monitoring for particulates or have onsite or perimeter environmental air monitoring stations that were designed to detect radioactive particulates. According to NIOSH (Section 4.3.2, "Source Terms for Internal Dose"):

> *No onsite environmental sources or outdoor concentrations of radionuclides have been reported for SNL/CA before the beginning of operations of TRL in 1979.*

NIOSH states that they used "absolute" filters in four buildings to attempt capturing radioactive particulates before being released in the effluents. Even if these filters were equivalent to HEPA filters or other highly rated filters, it is standard practice that any exhaust stack/vent that potentially releases airborne radionuclides, whether filtered or not, is monitored or sampled at a frequency determined to be adequate to verify releases are within limits and kept ALARA. Additionally, air sampling stations are typically placed at locations of expected highest concentrations, with near-critical receptors (such as at boundaries and near populations or buildings) for verifying that stack effluent controls and monitoring systems are operating properly. Without these, verification that effluent controls (e.g., "absolute" filters) are performing properly cannot be done, and it becomes more of an assumption that there were no airborne radionuclide effluents from these stacks. NIOSH should perform further verification that there were no possible onsite particulate radionuclide air emissions to which unmonitored workers were exposed.

Finding S4: The assumption that environmental TLDs placed significant distances from the locations that unmonitored personnel were exposed are representative of their maximum external doses may be inaccurate, and there are an unexplained low dose and other irregularities in the tables of gamma and neutron external doses.

NIOSH assumes that all external exposures to unmonitored staff were from LLNL site operations and can be assigned by assuming the LLNL perimeter TLD results are the maximum external dose to unmonitored staff from effluents and any other sources. This is reasonable if, and only if, maximum exposures could have been from only LLNL effluent releases and neutron fields. NIOSH bases much of this assumption on a 1975 aerial survey (Tipton 1977) that found the only "gamma-emitting radioactivity in excess of background levels" to be in areas that had access limited (NIOSH appears to be inferring that limited access means no unmonitored employees could enter these areas). Several of the sources of photon-emitting radiation at the site were x-ray machines and accelerators, which only would have been detected by the aerial survey if it had equipment capable to detect these (x-ray machines and accelerators can have very short pulse times and be difficult to detect with standard monitoring equipment) and if the machines and accelerators were operating during the survey. The site operated for approximately 30 years past this survey date and it is possible that more gamma-emitting sources, x-ray machines, and/or accelerators were acquired during those years that could have increased environmental external radiation hazards. NIOSH should verify that this 1975 aerial survey applies to all external radiation conditions from 1956–2004. As mentioned in Finding 3, no stack or ambient particulate radionuclide monitoring was performed at SNL CA; therefore, there was no total verification that DU was not released from their operations. DU has a strong beta emitter in its decay chain (Pa-234m, which grows into equilibrium with the U-238 activity within a few months after aging), which could give very large skin doses if a particle lands on the skin. This provides further emphasis that NIOSH should verify that no particulate radionuclides could have been released from site operations.

In Table 4-4 ["External gamma radiation dose based on 2,500 hr/yr exposure duration (mrem/yr)"], the dose for 1967 (15 mrem/yr) is less than one-tenth (1/10) of the dose for the prior year and following year (both 156 mrem/yr). The 1967 dose is the lowest annual dose in the site history shown in this table, and it is embedded in a period of much larger doses in the years nearest to it. NIOSH needs to either correct this dose in the table if it is a typographical error, or explain why it deviates so much from doses in the years before it and year after it.

There are also several "Maximum Dose Rate" values that do not agree with the sum of the "Average Perimeter" and "Error," from which NIOSH states the Maximum Dose Rate is derived. For example, in 1991, the Average Perimeter is 16 mrem/yr and the error is 5 mrem/yr, which sums to 21 mrem/yr for the Maximum Dose Rate, and the table has 20 mrem/yr shown in the column. This also occurs in Table 4-5 ("Elevated neutron dose due to LLNL perimeter neutron source"), where the summation of "North perimeter dose" and "Error" do not always add up to the value in the "Maximum dose" column. NIOSH should correct these summations, or if there is a reason for these to not sum directly to the actual values due to "rounding" up or down, it should be so stated.

Finding S5: NIOSH states that all airborne tritium releases and resulting intakes should be assumed to involve tritiated water (HTO), although the site handled various forms, because its mission involved research on tritium compounds.

At SNL CA, various chemical forms of tritium were fabricated and handled as metal tritides and likely several other chemical forms. Tritium was handled often in gloveboxes, which infers that any of these forms got airborne and presumably into the exhaust ventilation systems. NIOSH should defend the assumption that all intakes from environmental releases of tritium are in the form of HTO and not other forms that would result in different organ doses.

(1) NIOSH has assumed that there were no SNL CA-generated particulate radioactive airborne emissions of significance, which is somewhat unverifiable because of the lack of monitoring data.

(2) The assumption that environmental TLDs placed significant distances from the locations that unmonitored personnel were exposed are representative of their maximum external doses may be inaccurate, and there is an unexplained low dose and other irregularities in the tables of gamma and neutron external doses.

(3) NIOSH states that all airborne tritium releases and resulting intakes should be assumed to involve tritiated water (HTO), although the site handled various forms, because its mission involved research on tritium compounds

Finding S6: Protocols describing the frequency and type of x-ray examinations for SNL CA workers from 1956 to the present has not been located. Information is absent from the site profile, including types of x-ray equipment, technique factors, filtration, whether screens and grids were used, and some machine calibrations.

Although default protocols have been established for frequency and type of occupation medical x-rays, SC&A would like to stress the importance of reviewing the claimant-specific x-ray information, which may deviate from the standard assumptions. For example, lumbar spine x-rays were taken after employment of the individuals at times. It appears this was associated with a specific project or job. Individuals assigned to Site 300 were also given special exams; however, the details of these exams were unavailable.

As a result of the lack of medical x-ray information, the site profile relied on a review of the claimant medical records to ascertain the frequency and types of x-rays (ORAUT 2007a):

> *However, claimant files available at the time of this documents preparation generally indicate that a single posterior-anterior (PA) chest x-ray examination was performed at hire, annually, and possibly at termination from 1956 through the 1980s. They also show that anterior-posterior (AP) and lateral (LAT) lumbar spine x-rays were at least sometimes performed at hire as late as 1971.*

SC&A was able to obtain information regarding the medical x-ray program. The method for determining who was included in the health surveillance program at SNL CA has undergone changes through time. Radiation workers were included in those workers who participated in the health surveillance program. For the purposes of determining whether workers should participate in the health surveillance program, SNL CA defined a radiation worker as (Wright 1979):

> *A "radiation worker" at SLL [Sandia Laboratories Livermore] shall be defined as an employee who receives or could potentially receive radiation exposure from his job in excess of 10% of the applicable standard from internal or external radiation. This includes the following categories of personnel.*
>
> 1. *Those individuals working with ionizing radiation producing equipment or sources as part of their job and must enter restricted or controlled areas as defined by 10 CFR 20.*
>
> 2. *Those individuals working with radioactive materials which present a potential exposure as an internal emitter of radiation (except D-38).*

In 1982, Lovell indicated the following in a memorandum to Dr. Rhodenbaugh (Lovell 1982).

> *Based on codes and regulations followed by DOE, medical surveillance is recommended on the basis of some demonstratable exposure. This exposure level is normal at 10 to 50% of the permissible exposure limit. For example, those exposed to ionizing radiation would require medical surveillance if dosimetry indicated a 10% permissible level (500 mR/year) by internal or external dosimetry. Most toxic chemicals have a trigger level at 50% of the TLV [Threshold Limit Value] based on TWA [time-weighted average] of the airborne contaminant. For example, medical surveillance would be required for perchloroethylene exposure at 25 ppm [parts per million].*
>
> *SNL CA has taken a more conservative position and focuses on "exposure potential." If there is a potential for exposure with a plausible exposure mechanism, medical surveillance is requested.*

In 1987, the DOE Office of Nuclear Safety, DOE/HQ, entered into an interagency agreement with the Food and Drug Administration (FDA) to acquire third-party health physics surveys of medical diagnostic equipment. DOE Albuquerque Operations Office (DOE-AOO) notified its contractors that the Center for Device and Radiological Health would provide surveys at a 2-year frequency, and that documentation of these surveys would be provided to DOE-AOO and the contractor (Themelis 1987). SC&A located documentation on a survey conducted on September 13, 1988, of the medical x-ray unit at SNL CA. The unit was tested for reproducibility, linearity, filtration, collimation and x-ray/light field alignment. Stevenson (1988) stated in his survey report:

> *The skin entrance exposure (ESE) for a 26 cm P/A chest at 110 kVp, 300 mA and 1/60th of a second was 14 mR. There was no technique factors listed for the 23 cm chest, but the ESE at 110 kVp, 150 mA and 1/40th of a second was 10 mR.*

This would indicate that PA chest x-rays were being taken on some workers until at least 1988. Furthermore, there is data available of x-ray surveys for at least some periods of time, which serve to validate assumptions made in the site profile. This data should be used wherever available to derive occupational medical x-ray exposure doses.

One concern noted during the evaluation of individual medical records on the Request for X-ray Exam form for the early 1960s was the option for a “large chest” or “small chest” x-ray. Photofluorography film is smaller than the standard x-ray film. The meaning of “small chest” procedure needs to be defined to ensure this is not indicative of photofluorography use at the site.

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

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

4.1 OBJECTIVE 1: COMPLETENESS OF DATA SOURCES

Internal and external dosimetry records form the primary basis for conducting dose reconstruction. A quality assurance review of the data received from the site is critical to ensuring appropriate and complete records are provided for consideration in the dose reconstruction process. A preliminary review of claimant files indicate gaps in the external monitoring data, particularly for those years were the policy was to monitor all workers at the site. Limited internal monitoring data is available for Sandia in the individual radiation and/or medical file. Sandia has not provided cycle-by-cycle badge data, or in some cases, annual data. Much of the data provided is cumulative and may or may not include radiation exposure received offsite. Generic logbook data is available to fill some of the gaps identified in the claimant files; however, there is no direction to the dose reconstructor to consult this data.

The site profile inadequately characterizes offsite work activities involving SNL CA workers, which were extensive for some categories of workers. The impression presented in the site profile and within Sandia documentation is that host sites monitored Sandia visitors appropriately for internal and external dose during their visit. Furthermore, it is assumed this data is readily available through either the Sandia or visited sites. The data is lacking in SNL NM records requests, as well as those from visited sites. Travel offsite potentially exposed workers to plutonium, thorium, MFPs, MAPs, and other radionuclides without the benefit of internal monitoring in most cases, either at the visited site or upon return to SNL CA.

NIOSH identifies offsite visits through the CATI process and requests dose from the host site where a visit is captured in the CATI. If information on site visits is not specifically provided by the claimant, no information for offsite exposure is requested. Total reliance on the CATIs for offsite visits, particularly in the absence of a question related to these offsite visits, creates inconsistencies between survivor and energy employee claimants. Consideration should be given to alternative ways to identify visits to other DOE sites. Some thought needs to be given regarding how visitor records are requested from DOE sites, as visitor data is often stored separately from regular employee data.

In addition, it was noted that monitoring was not located for Sandia workers at a majority of the host sites. A brief review of exposure information retrieved for specific claimants and radiation exposure summary reports available on the SRDB indicate most of the data was external dose, with a limited amount of tritium data found for LLNL. A review of the claimant SNL CA dosimetry files indicated that in only a few circumstances was the offsite exposure data included in the SNL CA dosimetry file. In some cases, the monitoring dates and information provided by host sites did not correspond to the monitoring information available in the Sandia dosimetry reports.

4.2 OBJECTIVE 2: TECHNICAL ACCURACY

The site profile does not adequately address issues associated with the implemented dosimetry systems and the characterization of external exposure at SNL CA. There is a lack of information on dosimetry systems implemented at SNL CA prior to 1989, including uncertainties related to the dosimetry technology, dosimetry calibration procedures, dose calculation algorithms, adjustments to recorded dose, dose recording policies and practices, and uncertainty and bias factors. Furthermore, there is a lack of information on the MDLs and exchange frequencies. As a result, in the case of assignment of missed dose and dosimetry uncertainties, surrogate data from the dosimetry programs at ORNL, LLNL, Hanford, and BNL were used to estimate parameters for SNL CA. Discussion of data equivalency in the site profile between the dosimetry programs at these sites and SNL CA is inadequate and further demonstration of equivalency is necessary. This is particularly prudent, given discussions regarding use of surrogate data from other sites at the Advisory Board meeting in February 2010 (ABRWH 2010).

Issues have been raised in SNL CA documentation and the site profile regarding the ability of SNL CA to discriminate between radiation types encountered by SNL CA workers. The characterization of radiation energies and relative percentages provided in the site profile are based on estimates provided by site personnel, and on the assumption that tritium and DU were the primary source terms. The estimated energies and percentages are not substantiated by actual field measurements. Furthermore, external exposures from other radionuclides (e.g., Kr-85, EU, and MFPs) and operations (e.g., classified work) are not considered. In the absence of a reliable radiological characterization of the source term, the relative impact in inadequacies in the SNL CA dosimetry system is unknown. The need for a correction factor to account for the inadequacies of the dosimetry system to discriminate penetrating and non-penetrating exposures requires further investigation.

The variety of neutron sources and operating conditions at SNL CA warrant further characterization of the neutron energies encountered at SNL CA. Table 6-4, "Selection of radiation energies and percentages," indicates that at least some fraction of neutrons were less than 1 MeV (ORAUT 2007a, pg. 65). It is reasonable to assume that regardless of the initial neutron energy produced from a source or neutron generator, the spectrum to which workers were exposed would contain neutron energies less than 1 MeV. This is consistent with information from other DOE sites with similar operations. While the site profile considers a correction factor for conversion from NCRP Report 38, Neutron Quality Factors, to ICRP Publication 60, Radiation Weighting Factors (ORAUT 2006a), it does not consider the lack of, or reduced response of, NTA film to neutron energies less than 1 MeV. An appropriate correction factor or alternate methodology should be included in the site profile to compensate for the under-response of NTA film to low-energy neutrons.

Several SNL CA documents lead to the conclusion that radionuclides other than tritium and uranium were handled at SNL CA. The site profile itself indicates that Pu-239 and MFPs were handled in at least trace amounts (ORAUT 2007a, Table 2-1). Details on the quantities, forms, and handling conditions deserve further consideration in the site profile. With the presence of these radionuclides, and the absence of bioassay data for radionuclides other than tritium and uranium, consideration needs to be given to potential missed dose from exposure to these radionuclides. Furthermore, an investigation into radionuclides handled as a part of classified activities is warranted to ensure that potential exposure situations to other radionuclides did not exist. In addition, the SNL CA internal monitoring programs did not provide coverage of potential exposures to radionuclides encountered at other sites, including plutonium, thorium, MFPs, MAPs, and other radionuclides. The site profile assumes individuals were monitored at the visited site; however, very limited internal monitoring data has been recovered from other DOE sites. The existing bioassay program at SNL CA would provide adequate coverage to internal exposures received offsite in most cases.

The site profile fails to adequately consider potential uptakes of STCs. These compounds were generated during the course of experimental activities, and as byproducts resulting from the absorption, reactivity, and diffusion of tritium into structural material and chemicals used in the tritium processing areas. Compounds range from soluble to highly insoluble. Much of the work was conducted in engineered enclosures (at least at the TRL); however, there was a potential for exposure during the removal of tritium beds from gloveboxes, handling of tritium in unenclosed systems (allowed for small quantities), assembly and storage areas, waste handling, during system maintenance and repair, and during D&D of tritium facilities. In addition, there were conditions when there were lapses in radiological control. Assumption of an intake of HTO in place of STCs can underestimate dose by orders of magnitude, depending on the type of STC. Given the existence of STCs at SNL CA, further consideration needs to be given to potential exposures and resulting doses from these STCs. Currently proposed approaches developed by NIOSH for estimating dose from STCs rely on the use of urine bioassay results in concentration (e.g., µCi/L) and the ability to identify workers exposed to STCs. The site profile should discuss in detail how they will estimate dose from STCs, particularly those compounds not readily disassociated to soluble compounds in the body. Furthermore, the solubility type assigned for uranium tritide should be consistent with available literature and assumptions made in other site profiles and dose reconstruction documentation.

With respect to the adequacy of the uranium bioassay program, the uranium detection limits recommended in the site profile for the period 1973–1987 appear to be too low for analysis by fluorometry. The values proposed are well below the industry standard for this technique for this period of time. Uranium urinalysis samples collected from CEP (1990–1993 as defined in the site profile, and 1992–1994 as defined by SNL NM contract) is suspect and cannot be used for the determination of uranium dose or for inclusion in a coworker model. Solubility assumptions require update and correction based on currently available scientific data. The assumption for a mass conversion factor should be reflective of all enrichments of uranium handled at SNL CA, and not limited to DU. Defaulting to DU for conversion to activity when using bioassay data in units of mass concentration (µg/l), when the site handled NU and EU, would cause an underestimation of dose for those individuals exposed to normal or EU.

4.3 OBJECTIVE 3: ADEQUACY OF DATA

The Sandia TBD describes bioassay results from a commercial laboratory, CEP, that were invalidated based on the results of quality control samples and other data integrity issues (ORAUT 2007a, pg. 59). No explanation is provided, however, on how the TBD will address acute uptakes that may have occurred during this time period. Considering this was the only source of uranium data for SNL CA workers for 1992 to 1994, and possibly from 1990 to 1991, a methodology for addressing missed dose during this period should be developed.

4.4 OBJECTIVE 4: CONSISTENCY AMONG SITE PROFILES AND OTHER NIOSH DOCUMENTS

Sandia was actively involved in testing activities at NTS (including TTR) and in some cases PPG. Special Exposure Cohort (SEC) classes have been established for both NTS and PPG. Sandia personnel participated in equivalent activities as PPG and NTS employees. The eligibility of national laboratory participants in weapons testing SEC classes requires clarification and should be considered in the site profile. In addition, consideration should be given to how the weapons laboratory workers may be affected by other existing SEC classes at Mound, LANL, LLNL, Mound Laboratory, IAAP, Amchitka Island Nuclear Explosion Site, the Y-12 Plant, and RFP. The inadequacies in monitoring data identified at these sites existed for Sandia visitors, and onsite monitoring was not adequate to mitigate this situation in many cases.

Other site profiles have established methodologies to compensate for the lack of response of NTA film to low-energy neutrons. This is absent from the SNL CA site profile, although the potential for neutron exposure was present at SNL CA, and the laboratory had a neutron monitoring program.

4.5 OBJECTIVE 5: REGULATORY COMPLIANCE

No regulatory compliance issues were identified by SC&A in the SNL CA site profile.

4.6 AMBIGUOUS DOSE RECONSTRUCTION DIRECTION

In regard to external dosimetry, the site profile identified several uncertainties and concerns regarding dosimetry technology, calibration, dose calculation, and recording practices (refer to Finding 4). Directions guiding dose reconstructors to account for these uncertainties were cursory, at best. For example, in Section 6.4.2.1, the site profile acknowledged that a transition from film to TLDs may have occurred sometime between 1966 and 1972. To assure a claimant-favorable estimate of missed dose in light of this uncertainty, the site profile recommends assuming that film dosimeters were used until about 1972 in cases where missed dose is estimated. No specific guidance is provided regarding appropriate corrections to apply for the film dosimeter's MDL and exchange frequencies. Additionally, no guidance is provided for situations in which annual or badge cycle data is unavailable (cumulative exposures only).

Guidance is absent or ambiguous in regard to the absence of calibration data and methodology prior to 1989, the absence of dose calculation and reporting practices prior to 1989, and application of surrogate bias and uncertainty factors adopted from the Hanford site profile. No practices are identified to address the concern regarding energy discrimination deficiencies of the 2-chip, single-filter TLD badge used from 1972–1982.

Table 6-2 (page 62) identifies circumstances and protocols for dose adjustment or estimation, but the instructions for dose assignment are vague.

4.7 UNRESOLVED POLICY OR GENERIC TECHNICAL ISSUES

General policy issues, such as consistency in SEC process determinations and applications, are critical to sets of SNL CA workers conducting radiological activities at sites where classes have been previously established (e.g., NTS, PPG, Mound, RFP). Quality assurance of the claimant data provided to NIOSH by some facilities (including SNL CA) is insufficient and requires further consideration by NIOSH. The retrieval of monitoring records for DOE site visitors is another issue that requires further evaluation; some DOE sites appear to be inherently unable to identify and retrieve visitor monitoring data. Finally, it is paramount that NIOSH conduct outreach efforts and site expert interviews to gather pertinent information on site activities for each site profile, regardless of the size of the facility's claimant population.

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ATTACHMENT 1: SUMMARY OF SITE EXPERT INTERVIEWS

INTRODUCTION

As a technical support contractor assisting the Advisory Board on Radiation and Worker Health (Advisory Board), SC&A has been tasked with reviewing NIOSH's site profile for Sandia National Laboratories – Livermore, California, site. One component of SC&A's review is a series of interviews with site experts, including current site workers, former site workers, and worker representatives. The purpose of these interviews is to obtain first-hand accounts of past radiological control and personnel monitoring practices in order to better understand how operations and safety programs were implemented at the site over time. Interviewees were identified through available site reports, other interviewees, and site personnel. This report summarizes the results of those interviews that were reviewed and accepted by the interviewees.

SC&A representatives, Kathryn Robertson-DeMers and Robert Bistline, conducted interviews at SNL CA in Livermore, California, between June 8 and June 12, 2009. No Advisory Board members participated in these interviews. Additional SNL CA site expert interviews were conducted during a data retrieval effort at SNL NM, where SNL CA dosimetry records are stored. One interview was conducted via telephone on June 28, 2009. A total of 10 site experts were interviewed.

The workers whose interviews are summarized below represent the time period from 1959 through 2009. Their work involved all elements of weapons design, development, and testing, as well as energy research. One SNL CA interviewee also worked at Lawrence Livermore National Laboratory (LLNL) in areas relevant to the review of the SNL CA site profile. The programs and facilities represented by the interviewees include the following:

- Combustion Research Laboratory
- Division Management
- Environmental Management
- Energy Research and Development (Solar Energy)
- Maintenance and Crafts
- Radiological Operations and Dosimetry
- Research and Exploratory Chemistry (Chemistry Division)
- Site Historical Research
- Strategic Defense Initiative (SDI)
- Tritium Research Laboratory (TRL)
- Weapons Research and Development
- Weapons Engineering and Technical Support

Several interviewees participated in offsite work for SNL CA at other DOE Complex and military sites (refer to the Offsite Radiological Activities section for details).

SC&A explained that the interviews were being conducted on behalf of the Advisory Board as part of their review of NIOSH's site profile report. Due to the potential for disclosure of classified information, interviews were conducted in a secure location appropriate for classified discussions. Notes from these interviews were subsequently reviewed and cleared by SNL CA classification staff. Summaries from each interview set were prepared and provided to the interviewees for review. Approximately 30% of the participants did not respond to the request for review; the information obtained from non-responders has been withheld from this master summary.

The information provided by the workers and site experts is invaluable in helping SC&A better understand the operations at SNL CA. This summary report is not a verbatim presentation of the material contained in the interview notes, nor is it a statement of SC&A findings or opinions. It is a consolidated summary of statements, opinions, observations, and comments that the interviewees communicated to SC&A. Its sole intent is to communicate to the Work Group, the Advisory Board, and other interested parties information acquired by SC&A during these interviews. ***Comments in brackets indicate clarifying statements made by SC&A.***

Information provided by the interviewees is based entirely on their personal experience at SNL CA; the site experts' recollections and statements may need to be further substantiated. However, they stand as critical operational feedback and reality reference checks. These interview summaries are provided in that context. Key issues raised by site experts are similarly reflected in our discussion, either directly or indirectly. Interviews from all workers who reviewed and approved their individual interview summaries were consolidated into a single summary document. The information has been categorized into topical areas related to onsite operations, offsite radiological activities, radiological controls and monitoring, environmental monitoring and waste management, occupational medical exposure, incidents and unusual occurrences, comments on the site profile, and miscellaneous comments. Where conflicting observations and statements have been received, both perspectives have been retained in this summary report.

With the preceding qualifications in mind, this summary has contributed to SC&A's understanding of issues raised in the site profile review report.

SNL CA OPERATIONS

The Livermore facility was established in March of 1956 and is still in existence today. SNL CA was set up to support the weapons development of LLNL. SNL CA provided and continues to provide support to the weapons design and development conducted at LLNL. LLNL was responsible for all work on the physics package; Sandia was responsible for the mechanisms that made it work. Sandia provided design and test support, conducted tritium research supporting neutron generation, and later performed solar energy and combustion research. They were also involved in the trajectory portion of the weapon; the electrical systems; arming, fusing, and firing mechanisms; warhead interfaces; GE re-entry systems; and materials research. The lab also does some field testing of equipment. Sandia participated in stockpile surveillance testing, where weapons/components are randomly removed from the field for testing (such as non-destructive analysis). Because of the lack of historical knowledge, former SNL CA employees have been asked to provide consultation services for safe dismantlement of older weapons.

SNL CA had its own Vice President. There were about 800–1,000 employees there at the peak. Information on the numbers of employees is available for some years. The division numbers associated with the California site are the 8000 divisions.

Much of the work performed by SNL CA operations staff was secret. SNL CA engineers developed a series of components that permitted the Minuteman to go nuclear. These components would allow the tritium to dump into the pit during the explosion. This work was done in collaboration with LRL [Lawrence Radiation Laboratory]. Other work involved working with different components, such as valves. Collectively, interviewees worked on the Minuteman, the Hawk, the Lance, the 8" Artillery Shell, the Spartan, the Peacekeeper, and the W-89 programs.

There were several phases in the design of a weapons system. In Phase I and II, personnel developed ideas for a weapon and created the design definition. Under Phase III, they developed prototype components and units. Phase IV starts the production of the weapons system for the arsenal. Not all weapons designs operated as intended and required troubleshooting. For example, there was an issue associated with the pit tube on the Minuteman.

At SNL CA, they formed project teams. The team worked on all aspects of weapons design and component exposures; they interfaced with the military. The Level One Manager worked with the LLNL engineers. LLNL was responsible for development testing (Phase II) [including effects testing of weapons components]. A prototype of the warhead was developed, and they would fly the prototype to simulate actual exposure conditions. SNL CA and LLNL worked together; they would build the warhead, ship it up to a military base, hook it up to the missile portion, and ship the test unit out to the testing area.

The Chemistry Division was involved in materials research and exploratory chemistry. The Solar Power Research group was involved in the Molten Salt Project. SNL CA was involved in the Strategic Defense Initiative (SDI), which evaluated materials for underground tests. In Applied Energy and Combustion Engineering, SNL CA developed techniques for remotely sensing materials in the atmosphere.

Work done at the CRF [Combustion Research Facility] is a collaborative effort with the Office of Science. The goal is to increase combustion efficiency by cleaning up engines and furnaces. This is done with the use of lasers and computer modeling. Only non-ionizing radiation is used in this area.

The weapons evaluation laboratory runs the non-nuclear parts through tests. There are functional tests of weapons, such as spins, vibration, etc.

Metallurgists were involved in conducting diffusion studies into metals. This work was done in combination with the Savannah River Site (SRS). They were looking at fracture mechanics of the vessels. The studies were concerned with this through the stem (where the highest permeation occurred). There is a steady-state release after a couple of years. There is diffusion of some gases at the reservoir and valve.

OFFSITE RADIOLOGICAL ACTIVITIES

Personnel from SNL CA and SNL NM traveled to other DOE sites frequently. Initially, Sandia Corporation employees worked on the LLNL site to provide support to LLNL. They conducted work at Site 300 and conducted some of their own testing there. There were some SNL CA individuals who were permanently housed out at Site 300 of LLNL and others that visited.

SNL CA was primarily established to support the weapons development program at LLNL, and this remained a primary mission throughout its history. There was a lot of crossover between SNL CA and LLNL, especially during the weapons production process. SNL CA personnel would physically visit the LLNL site. The level of interaction between SNL CA and LLNL was dependent on the particular weapons development program. Some workers accessed Site 300 in the context of their support of LLNL projects. An interviewee recalled one occasion in which Sandia personnel observed the hydroshot testing. SNL CA helped with the build-up of the unit, and LLNL performed the shot. Individuals were in the bunker at the time of the shot.

[In comparison to SNL NM], there were fewer people based at SNL CA, but they were just as mobile as those individuals at SNL NM. There was a lot of traveling back and forth between the two Sandia locations. The weapons group would also travel back and forth to other DOE sites. The activities also moved back and forth between SNL NM and SNL CA. For example, Livermore personnel would have tests run at SNL NM reactors. SNL CA employees may have overseen some of the testing done onsite at SNL NM at the TA-3 and Coyote Canyon facilities. They were also likely involved in testing done at the TTR. Individuals [from SNL CA] were involved in retrofits and design modifications. Travel to storage sites was primarily handled by SNL NM. Both Sandia facilities [SNL CA and SNL NM] were involved in the Plowshare project.

SNL CA technical personnel (Design Engineers, Electronics and Monitoring personnel, Quality Assurance Personnel, etc.) frequently traveled to other DOE sites where there was a potential for radiation exposure. Other facilities visited by SNL CA workers included the Mound Plant, RFP, NTS, TTR, the Pantex Plant, the Y-12 Plant, the Medina Plant, the Clarksville Plant, IAAP, the Pinellas Plant, KCP, SRS, LANL, ANL, PNNL, and military installations. Sandia personnel also visited production facilities that did not handle radioactive material. Visits could last from a day to several months. In some situations, workers visited a site multiple times.

Activities performed during offsite visits ranged from meeting attendance and tours to assistance with operational activities at the visited site. Engineers would have to transfer their knowledge to the production facilities, so staff involved in Phase III worked with the weapons production plants on a regular basis. For example, the original machining was done at SNL CA, but subsequent machining was performed at the production facility, where SNL CA workers would oversee the operation. Some SNL CA employees required entry into radiological areas at other sites; they performed activities associated with quality assurance testing, assembly and disassembly, weapons testing, and hydroshots. If DOD had issues, the SNL CA engineers may accompany them on a flight.

A Production Liaison for design and engineering at RFP was required to look at the process and quality assurance on the product. He visited the RFP once or twice per week; he toured production areas at the plant (Buildings 371, 779, 880, 881, etc.), reviewed tools, and went to the Plutonium Metallurgical Laboratories. They were concerned about the quality of the welds (morphology). He visited the Pantex Plant. He also visited Tonopah and SNL NM to test devices that contained uranium.

Pantex had the responsibility for assembly and disassembly. LLNL would assemble the nuclear package and turn the work over to SNL CA to finish the reservoirs, timing, fusing, etc. The unit could be bolted or bonded together. SNL CA was also involved in the surveillance of the weapons, fabrication of tools, disassembly, and final certification.

There were some underground tests at NTS to test the effectiveness of the components. Vulnerability and hardening testing was a big deal. Effects testing of weapons' components was performed. The weapon would explode, and the radiation would travel down to chambers where equipment was housed. The equipment was exposed to large amounts of radiation to see how it would handle the radiation. The horizontal tunnels had doors that sealed to prevent the radiation from escaping the line of sight pipes. SNL CA was not responsible for re-entries, but the equipment was recovered, and SNL CA would get the disassembled test equipment for evaluation. SNL CA was involved with Hudson Moon and Hudson Seal.

SNL CA workers provided oversight for the beryllium and copper valves work at the Kansas City Plant (KCP). Sandia personnel were also sent to Mound to oversee work with reservoirs. There was no neutron generator work conducted in California; New Mexico was involved with this.

JTAs [Joint Test Assemblies] are compiled by the military to make sure the interface still works. When JTAs are flown on a test missile, SNL CA makes sure the data is collected. The test squadron is responsible for dropping bombs at TTR. SNL CA recovers the units, and they are sent to Pantex for disassembly and evaluation.

One interviewee indicated that he "traveled all over the place." This individual was involved in quality assurance testing at the NTS and later did testing on the 8" Artillery Shell at the TTR. The interviewee visited Pantex several times and was involved in the assembly of the Minuteman and the 8" Artillery Shell. During his time at Pantex, the SNL CA worker did make entries into the igloos. The interviewee spent time at [LLNL] Site 300, where there was plutonium. He visited other sites, including the Y-12 Plant in Oak Ridge and Medina. He also went to other production facilities that did not handle radioactive material.

[Other personnel, in addition to the weapon teams, also travelled offsite.] A RadCon worker visited Pantex and made some trips to SNL NM. He was sent there to oversee the work they were doing and find ways to reduce dose if possible. At Pantex, this included entry into the cells.

RADIOLOGICAL CONTROL

There has always been a safety organization at SNL CA. Initially, health physics work was primarily conducted by a single individual. There was also an industrial hygienist, a Fire Marshall, and a couple of sample engineers. As time progressed, health physicists oversaw the operations, surveys, counting laboratory, bioassay, dose assessments, instrument calibration, source checks and other activities at facilities. [Specific responsibilities were delegated to the Radiation Protection staff.] Currently, the Health and Safety organization is imbedded into the line management.

One interviewee stated that he was responsible for radiological control at the TRL; two additional technicians covered the remainder of the site. Technicians were responsible for day-to-day radiological controls, including routine radiological surveillances. Technicians at TRL were also involved in the analysis of tritium bioassay samples. One interviewee recalls being escorted by radiological control staff when he went to TTR to take specimens.

When TRL was discontinued, the former TRL RadCon staff got involved in various RadCon projects and work planning for the site as a whole. Interviewees noted that additional RadCon personnel were hired as a result of the SNL CA Tiger Team assessment (DOE 1990).

Characterization of Source Term

Most of the exposure at SNL CA was from chemicals and heavy metals with some work involving uranium and beryllium. Uranium was primarily considered a chemical hazard. The mock-ups handled by Sandia personnel contained DU and potentially thorium.

The radioactive materials and devices used at SNL CA varied by program and location. In Building 913, they handled classified units, with some units undergoing modifications or retrofits. Depleted uranium (DU) and tritium components were changed. In Building 927, they have handled Co-60 and Cs-137 radiography sources. Historically, there have been some AmBe sources handled onsite. There was an AmBe source in Building 961 and a Cf-252 source in Building 941. Thorium was used as check sources for radiation detection instruments.
In Building 941, there are x-ray devices. Some interviewees worked with sealed sources, such as x-ray diffraction units.

SNL radiological activities included radiography, radiation generating devices (e.g., x-ray diffraction), and TRL. The major radionuclides of concern onsite were DU and tritium. SNL CA did not handle fissile material. Most of the potential radiological exposure occurred offsite.

The [weapon] design process does not involve radioactive material, but the testing phase involves radiation. There were test cells in Building 983. They used radiography sources to check prototype components and do calibrations. There were some radiation hardening studies done at SNL CA and SNL NM.

The SDI [Strategic Defense Initiative] program by Ronald Reagan (aka the Star Wars Program) did not require the use of radioactive material.

Most of the exposure at SNL CA was from chemicals and heavy metals, with some work involving uranium and beryllium. Uranium was primarily considered a chemical hazard. There was some machining of DU and beryllium in Building 913 in the 1950s and 1960s.

Other unsealed radioactive sources handled at SNL CA included some thorium oxide powder, trace quantities of natural uranium, trace quantities of low-enrichment uranium (gram values), and radioactive solutions for making standards. There were small research quantities of enriched uranium and plutonium handled onsite. Some Kr-85 was in storage for a period of time; the interviewees did not know how it was used.

SNL CA worked with tritides from time to time. As a result, SNL CA RadCon staff sat on the Stable Tritium Compound Working Group (Tritium F-cog) for a while. Primarily, SNL CA worked with protium and deuterium, then passed the tritide work to Mound and SRS.

External Monitoring

At one point in history, everyone onsite was monitored for external exposure. In the earlier days, more individuals were monitored than probably needed to be. Positive exposures did/do not occur often. Over time, the monitoring was reduced to those working with radioactive sources. During this period, the first-line managers determined who was monitored for external exposure. Those individuals that are likely to receive 100 mrem in a year are/were monitored. Neutron dosimetry was a component of the routine dosimeter.

Dosimeters were stored onsite. Most individuals complied with this requirement and did not take them offsite. You were not supposed to take your dosimeter with you to other facilities.

When Sandia personnel visited other DOE sites, the [destination] site was responsible for providing internal and external monitoring. For example, if they went to Pantex or NTS, Pantex and NTS were responsible for providing the monitoring. When workers visited other sites, they were sometimes assigned a dosimeter (i.e., film badge or TLD) by the visited site. For example, RFP and Pantex Plant assigned dosimeters to SNL CA workers. Any dosimetry reports from workers visiting other sites would be sent to SNL NM and not to SNL CA. Some interviewees do not recall being told to request monitoring at a visited site, or to request that internal and external monitoring results be provided to SNL CA.

When Sandia personnel went to DOD facilities, they wore the Sandia dosimeter plus a dosimeter provided by the DOD facility.

Internal Dosimetry

Internal monitoring is job-dependent and based on the potential for airborne radioactivity. Pre- and post-job samples are collected. Post-job bioassay is collected immediately after the end of the job.

Tritium bioassay sample analysis was conducted at the TRL facility by RadCon staff during the operating phase of the facility; RadCon workers were sampled [as well as operations workers].

The routine bioassay program for TRL required collection of at least weekly bioassay samples. These were sometimes more frequent for special projects. The bioassay sample analyses for tritium were completed onsite at SNL CA via liquid scintillation counting. SNL CA was also responsible for tritium dose assessment. Records for laboratory analysis and dose assessment were transferred to SNL NM.

Uranium urinalysis was completed for limited operations areas at SNL CA. A RadCon worker has submitted about one uranium bioassay in the past 10 years. Depleted uranium beds used at TRL were confined in vessels, so there was no need for routine bioassay sampling. Uranium urinalysis samples were shipped to SNL NM.

There is really not much dose received anymore at this site. When the interviewee first arrived, they were using more radioactive material, particularly tritium.

Workers were not sent over to LLNL for any type of internal monitoring.

The only offsite internal monitoring interviewees reported was receipt of a whole-body count at Pantex. At the time, Sandia personnel were working in the cells with the warheads and in machining areas. There was also pre- and post-job bioassay sampling [for this project]. At NTS, one interviewee was only assigned a dosimeter without any internal monitoring.

Radiological Surveillance and Contamination Control

The machining operation was enclosed and performed as a wet operation. They conducted air sampling during machining operations. There were routine surveys around the equipment to look for chips and fines. There was some contamination with DU and tritium at times. Depleted uranium would get into the nooks and crannies of the machines. This was a pretty sloppy operation until the Tiger Team came in. This resulted in improvements to the process.

Air sampling at the TRL included fixed and portable air sampling equipment to monitor the room air. These were Overhoff air monitors. In addition, there was air flow and hood airflow testing in at TRL. Occasionally, when people were working around high levels of tritium, technicians monitored their sweat for tritium activity.

Tritide operations were conducted in gloveboxes. An interviewee indicated there was no potential for exposure as a result [of these controls]. Other interviewees noted that tritium (gas and water) eventually permeates through the rubber gloves, seals, gloveboxes, etc. As a result, there was tritium contamination in accessible areas.

During the decontamination, decommissioning, and reuse project at TRL, everything was checked per a plan developed for this work. On rare occasions, they would have contamination outside the gloveboxes. The facility was so clean that workers were not even required [to wear] shoe covers or lab coats in most cases. During the D&D of TRL, the contaminated pump oils were the most challenging issue to deal with.

Surveys were conducted on the medical x-ray unit until the mid-to-late 1990s, when SNL CA got rid of the unit. These surveys were done on an annual or semi-annual basis. In addition, RadCon surveyed any industrial unit that generated x-rays or radiation. These were surveyed for leakage. A copy of the unit survey was sent to the owner of the x-ray unit. TLDs were used to check the pulse x-ray equipment. RadCon technical staff indicated that they had not identified appreciable contamination around radiation-generating devices or from leaking sources.

There was a period of time at SNL CA when individuals were allowed to smoke everywhere. This occurred mainly in offices adjacent to a lab, but in the same air space. However, personnel were not allowed to smoke in explosive handling and storage areas.

ENVIRONMENTAL MONITORING AND WASTE MANAGEMENT

In the earliest days, the overall environmental group was a part of a single department, Environmental Safety and Health. The environmental staff now works under both the Environmental Management and Environmental Operations departments. At an interim point in time, environmental monitoring was a part of Hazards Control.

Prior to the startup of TRL, SNL CA relied on LLNL for their environmental monitoring except for stack monitoring. LLNL also performed soil and vegetation sampling for SNL CA. LLNL was responsible for conducting environmental monitoring at Site 300. An interviewee indicated that LLNL site boundary samples would not be representative of activity at Site 300, because Site 300 was located 15 miles from the LLNL main facility.

There were five TLD monitoring locations onsite for measurement of ambient external dose located within the perimeter of the site. These date back to at least 1991. The TLD sites at SNL CA are separate from the LLNL results. LLNL results are used as a source of comparison. A background dosimeter is maintained in a pig in the laboratory.

Historically, most of the environmental monitoring at SNL CA consisted of monitoring for tritium at the TRL stack. The site used to have dosimeters and bubblers for tritium around the site for conducting environmental monitoring. Air and water samples for tritium are available for TRL back thru 1979. The sampling was specific for tritium. Samplers used a pump and silica gel as an absorber. The material was collected every 2 weeks and was analyzed through a distillation process. No particulate air sampling was conducted. There was also an ambient air tritium sampling network starting in the early 1990s and continuing until the shutdown of TRL.

There were a couple of soil and sediment sampling locations on the SNL CA site. SNL CA has environmental data for air, groundwater, storm water, and the sanitary sewer system.

The counting laboratory at SNL CA performed analyses on environmental samples, such as water, ambient air, and stack samples. There were other types of samples analyzed also. The groundwater and storm water samples are analyzed for tritium via liquid scintillation counting.

Annual environmental reports for SNL CA date back to the 1970s. Routine and incidental releases are included in the annual reports. Environmental releases occurred from TRL through time and are chronicled in various reports. There were some episodic releases up-stack from tritium labs when upset conditions occurred, such as a burp. Although there was uranium machining, release of uranium was not a concern, because this operation was contained at the source.

Interviewees were not aware of any substantial radiation spills to the environment. No outside radiation contamination areas are known. There were no issues with animals contaminated onsite. There were not that many sources of radiological material on the SNL CA site. The State of California does not do routine environmental monitoring at the site. They conducted some background sampling, and for a year or two, there was some dual sampling.

San Francisco Water Company provided drinking water; it was totally separate from any of the process water systems.

There is no radioactive waste burial onsite. The low-level waste from SNL CA was shipped to NTS. Other waste was sent to SNL NM. There was a Navy landfill where construction debris from the Navy and early LLNL were buried, but this did not involve radioactive or chemical waste. The paint yard inherited from the Navy had to undergo cleanup.

There was no incineration of waste at SNL CA. Uranium welding and machining was performed at SNL CA, but intentional burning of uranium chips or turnings, or any other material (except classified documents) did not occur at the site.

OCCUPATIONAL MEDICAL EXPOSURE

There was a requirement for an annual exam for personnel in the Field Testing Group and the Accident Response Group (ARG). There were chest x-rays every couple of years. Chest x-rays included a posterior-anterior shot. The frequency of x-rays has changed over time.

Building 911 (Medical) used to have their own x-ray machine. After SNL CA got rid of the medical unit [mid- to late-1990s], they sent workers over to LLNL or to a regular community medical clinic. More recently employed interviewees recall having physical exams onsite, but they do not recall receiving x-rays as a part of the exam.

SANDIA RECORDS

SNL CA maintains their Environmental Safety and Health records, project and program records, and technical reports. Sandia testing records could be located at both SNL CA and SNL NM. Photographs have been sent to SNL NM. The facilities office has the building drawings. Specifics on the material used and everything about the weapons programs would be classified. Sandia Corporation produced annual reports, which are classified and available through the corporate archives. Building files would likely list spills that occurred. In the annual budget reports, the SNL CA budget was separate.

Radiological records presently stored at SNL CA consist of surveys, source leak checks, Radiation Generating Device checks, etc.

Scientists and engineers were and continue to be encouraged to publish in journals. There are also period progress reports issued (i.e., quarterly, monthly, annually) and annual operating plans. These reports offer some detail on what was occurring onsite at a particular time and facility. There isn't a historical summary document discussing the health physics program at SNL CA.

One current employee reviewed his radiation exposure record and thinks information from [offsite] visits were reflected in his record.

INCIDENTS AND UNUSUAL INCIDENTS

[The incidents described by interviewees included both onsite and offsite incidents.]

Around 1965–1970, one interviewee was visiting the Mound Plant, working in radiological areas at one of the facilities. There was a valve hooked up so the tritium could be dumped into a Bell jar. The pressure in the Bell jar was too high and the lid lifted off the jar, dumping the tritium gas to the air. This contaminated the entire room and the personnel involved. All the alarms in the building went off, and the entire building had to be evacuated. There was also concern about release to the environment. There were 2–3 Mound people in the clean room. The interviewee was outside reaching into the area where the Bell jar could be handled. The individual recalls being required to shower and was told to go home and drink lots of liquids. The interviewee did not recall being asked for a urine sample at Mound; however, when he returned to SNL CA the next day, Medical conducted testing on his urine daily for 5 days.

About a year after the Minuteman warheads were sent to the silos, one interviewee was involved in an incident at RFP. Personnel were testing a new aluminum wire that had been affected by the plutonium. This was done by pulling the wire to test the valve. Because the wire was contaminated, involved personnel were required to strip down, shower, and be monitored. Bioassay samples were taken, but lung counts were not done. RFP indicated that they lost this interviewee's badge.

There was a tritium uptake at TRL while they were disassembling a component; the tritium had adsorbed on the outside of the vessel. This incident was documented in an investigation report. An interviewee received approximately 0.5 Rem; the highest individual exposure from this incident was 1.5 Rem.

NIOSH DOSE RECONSTRUCTION/SITE PROFILE COMMENTS

Some individuals expressed concern that the dose reconstruction paperwork returned to claimants is too complicated, and that it could not be understood. The dose reconstruction report does not contain enough information in the assessment to answer many questions. Concern was raised about the assumption that the sources at SNL CA were leaking sources.

NIOSH/ORAUT conducted two visits to SNL CA [as of June 2009]. One interviewee indicated that he was interviewed by NIOSH during their visit.

MISCELLANEOUS

- Illnesses identified as occurring among SNL CA workers include bladder cancer.
- Valley Fever was the biggest safety concern at the 300 Site [at LLNL]. Spores would cause lung infections.
- SNL used standard wording rather than code words. The only code word the interviewee was aware of was tuballoy.
- There was a release from LLNL in the 1980s.

REFERENCES RECOMMENDED BY INTERVIEWEES

(1) SAND97-8004-UC-402, *Characterization, Minimization, and Disposal of Radioactive, Hazardous, and Mixed Waste.*

(2) SAND96-8004-UC-407, August 1996 – Related to environmental release.

(3) SAND95-8216-UC-402, *Radiological Characterization Plan for the TRL*, SNL/CA

(4) SAND-2001-3742P, *The Combustion Research Facility: Model for a 21st Century Open User Facility*, Carlisle, R.P., Monetta, D.J., and Sparks, W.L.

Interviewees also recommended review of the facilities collection on buildings, Safety Material Handling and Movement inventories, and Environmental Restoration reports.