Draft

ADVISORY BOARD ON

RADIATION AND WORKER HEALTH

National Institute for Occupational Safety and Health

REVIEW OF THE NIOSH SITE PROFILE FOR LAWRENCE BERKELEY NATIONAL LABORATORY

Contract No. 200-2009-28555
SCA-TR-SP2010-0002

Prepared by

S. Cohen & Associates
1608 Spring Hill Road, Suite 400
Vienna, Virginia 22182

Saliant, Inc.
5579 Catholic Church Road
Jefferson, Maryland 21755

January 22, 2010

S. Cohen & Associates: ***Technical Support for the Advisory Board on Radiation and Worker Health Review of NIOSH Dose Reconstruction Program***	Document No. SCA-TR-SP2010-0002 Effective Date: January 22, 2010 Revision No. 0 – Draft
REVIEW OF THE NIOSH SITE PROFILE FOR LAWRENCE BERKELEY NATIONAL LABORATORY	Page 2 of 83
Task Manager: __________________________ Date: ____________ Charles Phillips	Supersedes: N/A
Project Manager: __________________________ Date: ____________ John Mauro, PhD, CHP	

TABLE OF CONTENTS

ACRONYMS AND ABBREVIATIONS

Advisory Board	Advisory Board on Radiation and Worker Health
AEC	Atomic Energy Commission
ANL-E	Argonne National Laboratory-East
AWE	Atomic Weapons Employer
Bq	Becquerel
CFR	*Code of Federal Regulations*
D&D	Decontamination and Decommissioning
DOE	Department of Energy
DOL	Department of Labor
DL	Detection Limit
EDE	Effective Dose Equivalent
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
ESE	Entrance Skin Exposure
GSD	Geometric Standard Deviation
HEP	High Energy Physics
HHS	Health and Human Services
HILAC	Heavy-Ion Linear Accelerator
IREP	Interactive RadioEpidemiological Program
keV	kilo electron volt; 1,000 electron volts
LANL	Los Alamos National Laboratory
LBNL	Lawrence Berkeley National Laboratory
LLNL	Lawrence Livermore National Laboratory
LOD	Limit of Detection
LRL	Lawrence Radiation Laboratory
LRL-B	Lawrence Radiation Laboratory Berkeley
MDA	Minimum Detectable Activity
MDC	Minimum Detectable Concentration
MDL	Minimum Detectable Level
MeV	Million electron volts
mrem	Millirem
NESHAPs	National Emissions Standards for Hazardous Air Pollutants
NIOSH	National Institute for Occupational Safety and Health

NOCTS	NIOSH OCAS Claims Tracking System
NTA	Eastman Kodak Nuclear Track Film Type A
NTLF	National Tritium Labeling Facility
NTS	Nevada Test Site
OBT	Organically Bound Tritium
OCAS	Office of Compensation Analysis and Support
ORAU	Oak Ridge Associated Universities
ORAUT	Oak Ridge Associated Universities Team
OTIB	ORAUT Technical Information Bulletin
PA	Posterior-Anterior
PFG	Photofluorography
POC	Probability of Causation
rem	Roentgen equivalent man
SC&A	S. Cohen and Associates
TBD	Technical Basis Document
TIB	NIOSH Technical Information Bulletin
TLD	Thermoluminescent Dosimeter
UC	University of California
UCB	University of California-Berkeley
WB	Whole Body
WBC	Whole-Body Counting

1.0 EXECUTIVE SUMMARY

This report provides the results of an independent review of the Lawrence Berkeley National Laboratory (LBNL) technical basis document (TBD) conducted by S. Cohen and Associates (SC&A). This review was authorized by the Advisory Board on Radiation and Worker Health (Advisory Board) during the Advisory Board meeting held in Augusta, Georgia, on December 16–18, 2008. The TBD, ORAUT-TKBS-0049 (ORAUT 2007), is the site profile developed by the National Institute for Occupational Safety and Health (NIOSH) for the LBNL site. This review was conducted during the period January 2009–October 2009, in support of the Advisory Board's statutory responsibility under the Energy Employees Occupational Illness Compensation Program Act of 2000 (EEOICPA). This authority includes the conduct of such reviews and advising the Secretary of Health and Human Services (HHS) on the "completeness and adequacy" of the EEOICPA program.

LBNL was founded in 1931 on the University of California – Berkeley campus. It was originally known as the University of California Radiation Laboratory. Throughout its history, LBNL has been operated by the University of California – Berkeley for the Department of Energy (DOE) and its predecessors. In July 1945, LBNL moved from the Berkeley campus to a 134-acre site in the hills to the east. LBNL began defense work in 1941, when the National Defense Research Committee appointed Ernest O. Lawrence to study the potential military uses of U-235. LBNL is alternatively referred to in reference documents as Berkeley Lab, Lawrence Radiation Laboratory (LRL), and Lawrence Radiation Laboratory – Berkeley (LRL-B).

The TBD was evaluated for its completeness, technical accuracy, adequacy of data, compliance with stated objectives, and consistency with other site profiles, as stipulated in the *SC&A Standard Operating Procedure for Performing Site Profile Reviews* (SC&A 2004). As "living" documents, TBDs are constantly being revised as new information, experience, or issues arise. The list of supporting documents that were reviewed by SC&A for this site profile review is provided in Attachment 1.

This review found that the site profile provides an inadequate overview of LBNL historical operations and the primary radiological exposure sources and conditions. The presentation and analyses of the available data were generally technically sound, but not succinctly presented and documented to allow for a comprehensive review. The period covered is large, as it is for several of the other DOE sites and, like other sites, the earliest data are absent. The TBD failed to fully address the exposure implications of all the various radiation sources to the degree necessary to allow a comprehensive assignment of historical doses, including missed doses.

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

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

Following the introduction and a description of the criteria and methods employed to perform the review, the report discusses the strengths of the TBD, followed by a description of the major issues identified during our review. The issues were carefully reviewed with respect to the five review criteria above. Thirteen of the issues were designated as findings, because they represent deficiencies in the TBD that need to be corrected, and which have the potential to materially impact at least some dose reconstructions. These findings are summarized below.

1.1 FINDING 1: INADEQUATE DOCUMENTATION OF HISTORICAL OPERATIONS AND SOURCES OF RADIOLOGICAL EXPOSURES

This review found that the site profile provides an inadequate overview of LBNL historical operations and the primary radiological exposure sources and conditions. The document lacks sufficient detail and analysis to provide comprehensive guidance to dose reconstructors. The period covered is large, as it is for several of the other DOE sites; however, the TBD failed to fully address the exposure implications of radiation sources to the degree necessary to allow a comprehensive assignment of historical doses, including missed doses.

The site profile covers six areas; the Introduction, Site Description, Occupational Medical Dose, Occupational Environmental Dose, Occupational Internal Dose, and Occupational External Dose. SC&A's review found that each of these sections was deficient in its presentation of the information available on the subject for LBNL. Site profiles for other DOE sites whose historical operations are equally or less complex and diverse are more complete and informative to their intended audience than ORAUT-TKBS-0049. SC&A has made this determination through a review of historical records and interviews with site experts.

Specific operations and facilities are not discussed in sufficient detail. A prime example of the lack of significant detail and information is the coverage of the National Tritium Labeling Facility (NTLF). This facility provided tritium-labeled compounds for biological and medical research. The NTLF handled large quantities of tritium in a great variety of chemical forms, including organically bound tritium (OBT) compounds (see Finding 3).

The site profile fails to discuss the accelerator program at LBNL. Since this is the major source of exposure to site workers, this represents a major exclusion. The site profile should discuss the historical development of accelerators at LBNL, and provide a discussion of the various accelerators developed and the potential for routine, unmonitored, and accidental exposure to workers from these sources.

1.2 FINDING 2: INSUFFICIENT INFORMATION FOR INTERNAL DOSE RECONSTRUCTION, ESPECIALLY DURING THE EARLY YEARS

There is insufficient information on bioassay monitoring before 1961, and the information on air sampling and building activities is not sufficient to calculate the workers' dose due to internal exposures. Workers were potentially exposed to a diversity of radionuclides at LBNL, as shown in Table 2-1 of the TBD. Table 2-1 is incomplete in relation to the periods of time and quantities of radionuclides that were handled in the different areas. In addition, Table 2-1 gives no references for the source of information included in the table.

Table 5-8 was derived for calendar years 2001–2004, based primarily on airborne release data reported under the National Emissions Standards for Hazardous Air Pollutants (NESHAPs). No indication is given of the methodology used to convert air emissions to radionuclide inventory. Table 5-8 is of limited value, because of its inability to relate exposures during the various periods of time to the 2001–2004 emissions.

Table 5-4 lists minimum detectable activities (MDAs) for in-vitro measurements, but is incomplete with regard to the totality of radionuclides and their MDAs that were handled at LBNL. The information on MDAs on the various periods is incomplete, posing a problem with the calculation of missed doses. Potential missed dose associated with inadequate bioassay techniques is not mentioned in this TBD. Discussions on the adequacy of monitoring techniques are missing, and the methods of analysis for many radionuclides are not specified; thus, the quality of the measurement techniques cannot be evaluated.

Gross alpha, beta, and gamma analyses are reported as being used for the entire site operation, including the present time. The TBD does not discuss the fact that many radionuclides present at LBNL would not have been detected by gross measurements, or at least detected with low recoveries and resulting high minimum detectable concentrations (MDCs). In addition, the use of gross measurements results in an indeterminate MDC for a specific radionuclide. The potential missed dose associated with non-specific bioassay techniques should be further investigated to determine the impact on internal dose calculations.

1.3 FINDING 3: SPECIAL FORMS OF TRITIUM AND PLUTONIUM NOT ADDRESSED BY NIOSH

NIOSH fails to identify in the site profile that metal tritides and organically bound tritium (OBT) are included in the materials used at the site, and that tritium was used extensively at LBNL, in particular at the NTLF, Building 75. There is very little discussion about tritium exposures in the internal dose section (Section 5.0) of the site profile. It was stated during the interviews that OBT and metal (at least uranium and titanium) tritides were handled at NTLF. Section 5.0 does not discuss specifically the frequency of bioassay sampling that was performed at NTLF, which is the most important parameter in performing adequate bioassay monitoring for tritium.

During the interviews, health physicists stated that it was possible that highly oxidized/high-fired forms of actinides were handled at the site. They stated that the most likely source of exposure to these forms would have been related to the production of sealed sources and targets that were made for use at LBNL and other national laboratories. It is possible that NIOSH is addressing this issue for plutonium exposures at LBNL; however, the site profile does not address high-fired forms of other actinides (thorium, uranium, etc.). NIOSH should update the site profile detailing how it will handle high-fired forms of actinides in dose reconstruction for this site.

1.4 FINDING 4: BIOASSAY DATA COMPLETENESS AND ADEQUACY HAVE NOT BEEN VERIFIED

During the site visit by SC&A, it was determined that the bioassay database does not contain all bioassay data for all workers. SC&A found bioassay data in old files during the records search, which LBNL dosimetry staff verified were not in the database; therefore; it appears that the database may be incomplete. In addition, bioassay submittals were delinquent by at least 1 year in some file records. This delay could increase the minimum detectable doses significantly, especially for soluble and short effective half-life nuclides.

In Tables 5-1 through 5-5 of the TBD, NIOSH listed many in-vitro and in-vivo bioassay methods, along with information on frequency of sampling. Given the great number of radionuclides that could have resulted in internal exposures at LBNL, it is apparent that many of these are short-lived relative to the bioassay frequency.

During the site interviews, it appeared that work conducted at the Donner Laboratory and other laboratories at the University of California – Berkeley campus was not monitored and/or controlled as stringently as at other LBNL facilities. NIOSH should investigate the possibility that internal dose information (bioassay and air sampling data) for the work at these laboratories is adequate to reconstruct doses at these locations.

1.5 FINDING 5: INSUFFICIENT JUSTIFICATION FOR SELECTION OF IREP ENERGY RANGE FRACTIONS FOR PHOTON EXPOSURES

In Table 6-2 of the TBD, beta and photon doses are assigned to energy ranges according to the radioactive materials used in individual buildings at LBNL. For Buildings 51 and 71, a single photon energy distribution is given, and 10% of the measured dose is assigned to the 30–250 keV range and 90% assigned to >250 keV. It appears that this photon energy distribution is being applied to the entire history of accelerator use at LBNL. It is questionable that this energy distribution is appropriate in all situations and timeframes. In the early years, it is much more likely that technicians and others would be exposed to low-energy emitters shortly after a machine was powered off, or even during operation. This was presumably less likely as energies and risks grew larger and commensurate standards and protective practices evolved.

Regardless of the precise fraction that should be assigned, the choice of less than 100% to the 30–250 keV category should only be made where there is supporting evidence. As it stands, the selection of a 10% fraction is not claimant favorable and not buttressed by the inclusion of supporting evidence. Although the other buildings have been assigned factors greater than 10% for the more claimant-favorable 30–250 keV photon energy range, the fact that the accelerator buildings have been assigned a single low factor creates doubt on the validity and process by which the other factors were determined for the remainder of the site. NIOSH should provide justification, other than, "…it was done in a manner similar to the LLNL and LANL facilities" for the assignment of the fractional factors in Table 6.2 of the TBD.

1.6 FINDING 6: INSUFFICIENCY OF NEUTRON DOSIMETRY TREATMENT

1.6.1 NTA Film Energy Threshold Determination

As has been the case in a number of site profiles prepared by NIOSH, there is an inconsistent approach to the energy cut-off for the NTA neutron dosimeter. Callout "c." in Table 6.5 references NIOSH 2002 as listing the NTA lower energy threshold at 500 keV, yet attribution number 47 discusses 800 keV as the threshold, and this is used as the basis for this TBD. Other sources list 1,000 keV as the threshold for NTA response. The assumption that NTA film responds down to 500 keV is not justified by the technical data and is not claimant favorable. This issue is especially important, as the field to which the individual was exposed is usually poorly characterized, and the neutron weighting factors are large and variable over the range of 0.1 to 2 MeV.

1.6.2 Failure to Adjust Recorded Doses to Correct for Lack of Response of NTA and CR-39 in the Intermediate and Thermal Neutron Energy Range

Table 6.6 of the TBD, "Adjustments to Recorded Dose," defines the corrections for photon and neutron dosimeters to adjust the measured quantity. However, no adjustment is indicated for the failure of NTA film to respond to intermediate energy neutrons. As presented, a significant part of the spectrum is inappropriately monitored and uncorrected.

There is virtually no discussion of the potential for neutron fields throughout this historical facility. Given that LBNL was a world leader in accelerator development, and given the leading-edge high energies developed by the machines, it is likely that there was the potential for unanticipated radiation fields and possible neutron exposures across a range of energies, especially in the early decades. Some discussion of this is called for in the TBD.

There is a remarkable silence as to thermal or slow neutron exposure in the site profile document. Only one mention of slow neutrons is made in the site profile document and that one is only made in passing (bold added for emphasis):

> *Dose reconstructors should use the electroscope results in a qualitative manner because no data were found on the calibration or energy response of these devices; they should use the film or TLD results to estimate the actual exposure or the electroscope reading if no corresponding dosimeter reading exists.* ***The electroscope results include daily readings in tables captioned "dosimeter," "slow neutron," and "electroscope."*** *The three readings, which occurred on the same dates, were evidently used to measure exposure at the end of work shifts….*

No other mention of slow or thermal neutrons is made. A search of the "O" drive revealed only a single document (referenced in the above paragraph) that mentioned slow or thermal neutrons. Clearly there was the potential for exposure to slow neutrons, as slow neutron electroscopes were in use in 1956 and readings were documented for several individuals. NIOSH should investigate the issue as a part of a broader look at the intermediate and slow neutron exposure potential.
It is unclear from the TBD how and when albedo TLD data were merged with CR-39 results. The gap in neutron response from above the cadmium cutoff to the lower energy threshold for CR-39 (also not mentioned, but assumed to be around 150 keV) is not discussed. NIOSH should evaluate the neutron program and determine how missed intermediate energy neutron dose should be determined for this period, as well as intermediate and thermal energy neutrons for the NTA and pre-NTA years.

1.6.3 Selection of Minimum Detectable Dose for CR-39 Dosimeters

Table 6-1 of the TBD shows that the MDL for CR-39 is 10 mrem, with no attribution provided. The Los Alamos TBD shows an MDL for CR-39 of 20 mrem. The current commercial service available from Landauer, Inc., also shows an MDL of 20 mrem. It is likely that the minimum detectable level for CR-39 is higher than 10 and more likely around 20 mrem. This number is important and it is likely to be amplified to take account of missed dose not only due to exposure below the detection limit (DL), but also to estimate dose due to lower energy neutrons that would have been missed entirely due to the inability of CR-39 to detect lower-energy neutrons.

1.6.4 Use of Neutron-Gamma Ratios for Situations Where Neutron Data are Lacking: Seeming Inconsistency Between the Environmental and External Dose Sections

Table 4.1 of the Environmental Occupational Dose section (Section 4.0) of the TBD contains estimates of annual environmental dose throughout the history of the facility. The values provided are totals of neutron and photon exposure.

The Environmental Dose section utilizes a ≥70% factor and the External Dose section utilizes a 42% factor. This significant difference in the average site-wide neutron-to-photon ratio is surprising. It is possible that the environmental dose includes more sky shine and other factors. However, this issue needs to be addressed and the large difference explained.

This section on the determination of missed and missing neutron exposure needs a thorough review. Both the source terms and the dosimeter response specifications need to be addressed.

1.7 FINDING 7: FAILURE TO JUSTIFY THE SHALLOW DOSE: DEEP DOSE ASSUMPTION

The TBD provides guidance on the dose to be assigned in the "early" years (pre 1979) for which there is no record of beta exposure. In the general case, there is an assumption that a factor of 3 for the ratio of shallow to deep dose is reasonable and claimant favorable. However, LBNL had a broad mandate, as the Site Description section states on page 8:

> *From the 1950s to the present, the laboratory has maintained its status as a major international center for physics research and has diversified its research program into almost every realm of scientific investigation.*

In most cases, the site description does not provide sufficient detail as to the quantities, forms, and methods under which these materials were handled. What is known is that the levels of protection in the 1940s, 1950s, and 1960s were far from what would be considered good practice today.

There is no mention of head and eye dose or non-uniform whole-body irradiation in the site profile. Typically, workers handling beta emitters and those performing maintenance inside accelerators can be exposed to significant non-uniform fields. Likewise, there is no mention in the TBD of potential skin and clothing contamination and resultant exposure.

It is unclear from the TBD if workers were exposed to significant shallow dose with possibly little deep dose to be used as an indicator. Possible activities that may have been conducted include fume hood operations, maintenance of accelerators, ventilation and plumbing systems, waste disposal operations, and spill cleanup. The lists of nuclides are extensive and include beta emitters, including some pure beta and low-energy x-ray emitters. For some personnel, the 3:1 ratio may not be claimant favorable. NIOSH should identify the workers who could have received exposure from these beta or low-energy x-ray emitters, or provide an alternative method of estimating the shallow dose in a claimant-favorable manner.

1.8 FINDING 8: UNCERTAINTY IN BETA-GAMMA DOSIMETER RESPONSE TO RADIATION TYPES AND ENERGIES

1.8.1 The Use of Early Electroscope Data Needs Greater Definition

Page 39 of the TBD describes the use of electroscope data as follows:

> *… LBNL began operations using dosimeter and processing technical support provided by the Metallurgical Laboratory at the University of Chicago. After 1952, LBNL operated its own fully functional personnel dosimetry program with in-house processing. Exposure data were recorded by film badges and thermoluminescent dosimeters (TLDs). Early exposure records also provided electroscope (or at times, electrometer or E was used) results, which supplemented the results measured by film. Dose reconstructors should use the electroscope results in a qualitative manner because no data were found on the calibration or energy response of these devices; they should use the film or TLD results to estimate the actual exposure or the electroscope reading if no corresponding dosimeter reading exists.*

A search of the "O" drive found that, anecdotally at least, there were significant problems with electroscopes. A study performed November 23, 1953, by Jim Bennett (Bennett 1953) showed that readings from the three electroscopes tested were widely divergent from the film that was exposed with them. Two gave a 10% response compared with the film, and the third was off scale. No details are provided as to the energy of the gamma source used for the exposure. However, the memo provides a cautionary statement as to using electroscope data even in a qualitative manner.

1.8.2 Dosimeter Response to Very High Energy Photons and Charged Particles

LBNL was a pioneer in the development of high energy physics (HEP) and in the search for exotic particles. The film and electroscopes in use in the early decades will likely not have been calibrated for energies above 1 or 2 MeV. NIOSH should evaluate the dosimetry and potential for exposure to radiation at energies above that commonly produced by radioisotopes. The detectors will have responded to some degree, but the correction factor size and sign are unknown and not mentioned in the TBD. The response of the detector element or film, for example, will depend greatly on the composition of the holder and filters.

1.9 FINDING 9: X-RAY EXPOSURES ARE UNCERTAIN

Table 3-1 lists the entrance skin exposure (ESE) doses used for the posterior/anterior (PA) chest exam. It states that, until 1975, all dose estimates are defaulted to those provided in ORAUT-OTIB-0006. There is no information identified as being available on x-ray equipment that was used prior to 1975. Depending on how one views this information, there is no indication that this default is claimant favorable for the years 1942 through 1975. NIOSH needs to better describe what measures were taken to determine what types of equipment were used. For example:

- Where did workers get exams between the years 1942–1975?
- Were medical records available and do they indicate if x-rays were taken?
- Were workers sent to alternate locations for exams and were those records researched?
- Did NIOSH research address the potential use of PFGs to screen workers up through 1960?

The TBD should be expanded in its discussion of the medical dose to address the issues indicated in the above questions in order to be considered complete.

1.10 FINDING 10: UNCERTAINTY OF CALCULATING DOSES PRIOR TO 1961

There is no information on how NIOSH is planning to reconstruct doses before 1961. In ORAUT-TKBS-0049:

- Table 5-1 lists the in vitro types of bioassay, the periods, and the frequencies of monitoring. It does not contain any information that might be applicable to calculate doses for exposures before 1961.
- Table 5-4 lists the MDAs for various analysis results. The only pre-1961 information available is the MDA for gross alpha, and gross beta is for 1957–1961.
- Table 5.8 contains only one reference to exposures before 1961.
- Looking at the files for LBNL in the NIOSH OCAS Claims Tracking System (NOCTS), 24 claimants received compensation. Those were probably the most exposed workers, and 18 of the 24 claimants started working before 1961. There is only one bioassay record before 1961; a uranium urinalysis done in 1958.
- Looking at the 99 claimant files for LBNL who did not receive compensation, 31 started working before 1961. There is only one bioassay record before 1961; a C-14 breath analysis performed after an incident in 1959.

There is insufficient information related to bioassay monitoring before 1961 in the TBD.

1.11 FINDING 11: INADEQUACY OF BIOASSAY ANALYSES PRESENTATION

There was a diversity of radionuclides at LBNL. The Occupational Internal Dose section of ORAUT-TKBS-0049 specifies that, "from 1960 to 1996, both in vitro and in vivo monitoring records and associated interpretations exist." On Table 5.4, MDAs are listed for gross alpha for isotopes of thorium, plutonium, curium, actinium, and neptunium. The same method and MDA is listed for Cf-252 from 1965–1995. There is a remark specifying that "method descriptions note that uranium, radium, and polonium are not detected by this method (Author unknown, no date)."

Table 5.8, "Radionuclides and fraction activity by facility," is incomplete and difficult to use, in relation to discrimination between exposures during the various periods of time the rooms were used in the installation.

In NOCTS, the files indicate that for the 24 claimants from LBNL that received compensation, 22 started working before 1969. Some claimants had just one bioassay record during their entire work life, which sometimes spanned to over three decades.

- Of the 99 claimants for LBNL in NOCTS who did not receive compensation, 59 started working before 1969. No in-vivo monitoring was recorded in the period 1960–1969.

- A document referenced in ORAUT-TKBS-0049, entitled, *Individual Bioassay Reports for Employees Beginning Last Name with A - 1965–1990*, indicates that only gross alpha is reported until 1968, and gross alpha, gross beta, and gamma are reported in 1969. The first whole-body counting (WBC) is reported in 1970.

- The document SRDB 21986, titled, *Terminated Bioassay Results of Employees With Last Name Beginning with A, 1961-1983*, and referenced in ORAUT-TKBS-0049, lists bioassay monitoring of 106 employees with last names beginning with A and B. Only gross alpha is reported from 1960–1966, with except for a WBC in one year. In 1967, gross alpha and beta are reported and a few people involved in accidents were monitored in the WB. In 1968, gross alpha and beta are reported, and in two instances, specific monitoring for actinides and Cf-252 and Am-241. In 1969, gross alpha, gross beta, and gamma urine counting are reported, plus one analysis of P-32 and C-14, and two WBC, one related to an incident.

Tables 5.1, 5.2, and 5.4 describing in vitro bioassay programs, methods, and MDAs are incomplete and do not give enough information on internal dose calculations for LBNL employees. Table 5.8 is also incomplete and difficult to use, in relation to discrimination between exposures during the various periods of time and the rooms used in the installation.

1.12 FINDING 12: FAILURE TO PROVIDE SUFFICIENT GUIDANCE FOR UNMONITORED WORKERS

The TBD fails to provide guidance on how to calculate doses to workers without a complete description of the monitoring programs (Table 5.1), and on how to assign monitoring results to specific radionuclides and compounds. The TBD admits that, for many of the radionuclides, there is no specific information on the compounds with which they may have been associated.

Insufficient guidance is provided on estimating internal doses for unmonitored workers. The information on bioassay programs is incomplete, as well as the list of radionuclides and compounds handled at the facility during the different time periods and in different locations. The TBD suggests that unmonitored workers should be assessed using coworker data and the tolerance levels, if there is evidence that they worked with uncontained radioactive materials; otherwise, environmental data should be used. This suggestion cannot be followed using the information available in the TBD.

NIOSH should revise the site profile document to provide information sufficient for proper dose reconstruction, particularly for unmonitored workers.

1.13 FINDING 13: INADEQUATE COVERAGE OF OCCUPATIONAL ENVIRONMENTAL DOSE

Section 4.0 of ORAUT-TKBS-0049, Occupation Environmental Dose, is incomplete and should be revised to provide a more comprehensive description of the historical environmental dose to workers at LBNL. The deficiencies and omissions are such that inadequate guidance is provided for dose reconstructors.

NIOSH uses the data reported from the site environmental reports for the years they are available (1959–2004) to generate Table 4-1 providing the external gamma and neutron doses for the site for the operational years. For 2 years, 2002 and 2004, the data were reported as "not detected," and NIOSH provided estimates by averaging the five previous years' results. In addition, no reports were available for the years 1942 through 1958. NIOSH used a parabolic curve method to estimate the gamma and neutron doses for these years. Both of the estimating methods seem appropriate and claimant favorable, given the time periods, rate of growth of the exposure sources, and the resulting estimates comparison.

NIOSH assumes that the gamma and neutron environmental exposure is primarily from accelerators and thus using the maximum measured value from the onsite and fence-line monitors for a given year would be claimant favorable. NIOSH fails to discuss the possible exposure of unmonitored workers from irradiators. In particular, the Co-60 irradiator housed in Building 74 may have been capable of higher doses at locations at distances less than those to the site perimeter or onsite monitoring locations (LBNL 1995a).

Table 4-2, "Maximum site-wide annual median intakes (Bq/yr) via inhalation," contains the NIOSH best estimates of annual intakes. Except for tritium and C-14, the values in the table are based on gross alpha and beta measured values from the site environmental program. The site profile states the following:

> *LBNL attributes gross alpha results to ^{232}Th and gross beta results to ^{90}Sr for the purposes of dose calculation; these assumptions should be made.*

The LBNL 1994 Environmental Report (LLNL 1995a) states the following:

> *Throughout this report, unidentified radionuclides are assumed to be ^{232}Th if they are alpha-emitting material or ^{90}Sr if they are beta emitting material. This is a*

> *conservative approach because these assigned radionuclides represent the most restrictive alpha and beta emitters listed in DOE Order 5400.5.*

While this may be a conservative assumption relative to the effective dose equivalent (EDE), this may not be claimant favorable for specific organ doses. For example, for exposure to I-131, where the committed dose equivalent per unit intake for the thyroid is almost two orders of magnitude greater than for Sr-90, the dose to the thyroid would be grossly underestimated. Given the wide range of radioisotopes used at LBNL, NIOSH should present a more claimant-favorable approach to dose reconstruction for radionuclides whose intakes were determined from gross alpha and beta measurements.

2.0 INTRODUCTION AND SCOPE

2.1 INTRODUCTION

This report provides the results of an independent review of Lawrence Berkeley National Laboratory (LBNL) technical basis document (TBD) conducted by S. Cohen and Associates (SC&A). The TBD reviewed makes up the site profile developed by the National Institute for Occupational Safety and Health (NIOSH) for the LBNL site. This review was conducted during the period January 2009–October 2009, in support of the Advisory Board on Radiation and Worker Health (Advisory Board) in its statutory responsibility under the Energy Employees Occupational Illness Compensation Program Act of 2000 (EEOICPA). This authority includes the conduct of such reviews and advising the Secretary of Health and Human Services (HHS) on the "completeness and adequacy" of the EEOICPA program.

LBNL was founded in 1931 on the University of California – Berkeley (UCB) campus by Ernest O. Lawrence. It was originally known as the University of California Radiation Laboratory. Throughout its history, LBNL has been operated by the University of California for the Department of Energy (DOE) and its predecessor, the Atomic Energy Commission (AEC). In July 1945, LBNL moved from the Berkeley campus to a 134-acre site in the hills to the east. LBNL began defense work in 1941, when the National Defense Research Committee appointed Dr. Lawrence to study the potential military uses of U-235. LBNL is alternatively referred to in reference documents as Berkeley Lab, Lawrence Radiation Laboratory (LRL), and Lawrence Radiation Laboratory, Berkeley (LRL-B).

Figure 1. Lawrence Berkeley National Laboratory

Under the direction of Dr. Lawrence, the first operating cyclotron was developed and, over the years, larger and more powerful particle accelerators were constructed to study basic atomic structure. The Laboratory also conducted basic radionuclide and biological studies.

LBNL originated in 1931 as an accelerator laboratory with the construction of a 27-inch cyclotron on the University of California-Berkeley (UCB) campus. In 1940, it was relocated to its present site. The first major facility was the 184-inch Synchrocyclotron. During the 1940s, LBNL experienced rapid growth due to national defense needs and several temporary wooden buildings were constructed. From 1948 until 1972, LBNL was known as Lawrence Radiation Laboratory and was funded by the AEC. Beginning in the 1950s, facility layout was better planned and permanent concrete and steel structures were constructed. In 1972, the name was changed to Lawrence Berkeley Laboratory. In 1995, the name was changed to Lawrence Berkeley National Laboratory (LBNL). LBNL has developed and operates a number of experimental facilities, including three large accelerators, several small accelerators, and radiochemical laboratories, of which the Human Genome Center, National Tritium Labeling Facility, and National Center for Electron Microscopy are a part. The future use of the facility is expected to be similar to its past and current use for energy-related research.

In performing this research, many types of chemicals, some radioactive and some hazardous, have been used in the operations at these facilities, or have been produced as waste from these facilities.

2.2 REVIEW APPROACH

Under the EEOICPA and Federal regulations defined in Title 42, Part 82, *Methods for Radiation Dose Reconstruction Under the Energy Employees Occupational Illness Compensation Program,* of the *Code of Federal Regulations* (42 CFR 82), the Advisory Board is mandated to conduct an independent review of the methods and procedures used by NIOSH and its contractors for dose reconstruction. As a contractor to the Advisory Board, SC&A has been charged under Task 1 to support 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 LBNL, ORAUT-TKBS-0049, *Site Profile for the Lawrence Berkeley National Laboratory, Rev. 01* (ORAUT 2007). A complete list of documents reviewed for this audit, including the TBD, is provided in Attachment 1.

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

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

- Assess NIOSH's use of the data in dose reconstructions

SC&A's review of the TBD focuses on the quality and completeness of the data that characterize 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 deriving dose reconstructions, bridging uncertainties, or correcting technical inaccuracies.

The TBD serves as a site-specific guidance document used in support of dose reconstructions. This site profile provides the health physicists who conduct dose reconstructions on behalf of NIOSH with consistent general information and specifications to support their individual dose reconstructions. This report was prepared by SC&A to provide the Advisory Board with an evaluation of the degree to which the TBD can support dose reconstruction decisions. The criteria for evaluation include whether the TBD provides a basis for scientifically supportable dose reconstructions in a manner that is adequate, complete, efficient, and claimant favorable. Specifically, these criteria were viewed from the position of whether dose reconstructions based on the TBD would provide for robust compensation decisions.

The basic principle of dose reconstruction is to characterize the radiation environments to which workers were exposed, and determine the level of exposure a worker received in that environment through time. In accordance with the requirements of 42 CFR Part 82, the hierarchy of data used for developing dose reconstruction methodologies is dosimeter readings and bioassay data, co-worker data and workplace monitoring data, and process description information or source-term data, respectively.

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) Introduction and Scope
(3) Assessment Criteria and Method
(4) Site Profile Strengths
(5) Vertical Issues
(6) Overall Adequacy of the LBNL Site Profile as a Basis for Dose Reconstruction

Based on the issues raised in each of these sections, SC&A prepared a list of findings, which is found in the Executive Summary and in Section 4.0. Issues are designated as findings if SC&A believes that they represent deficiencies in the TBD that need to be corrected, and which have the potential to have a material impact on at least some dose reconstructions. Issues can also be designated as secondary issues if they simply raise questions, which, if addressed, would further improve the TBD and may possibly reveal deficiencies that will need to be addressed in future revisions of the TBD. Eight secondary issues were identified in the LBNL site profile, and they are discussed in Section 4.0.

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

In some ways, the TBD was successful in addressing a series of technical challenges. In many areas, the TBD exhibits shortcomings that could potentially influence some dose reconstructions in a substantial manner.

3.0 ASSESSMENT CRITERIA AND METHODS

SC&A is charged with evaluating the approach set forth in the site profile that is used in the individual dose reconstruction process. These documents are reviewed for their completeness, technical accuracy, adequacy of data, consistency with other site profiles, and compliance with the stated objectives, as defined in *SC&A Standard Operating Procedure for Performing Site Profile Reviews* (SC&A 2004). This review is specific to the LBNL Site Profile, supporting technical information bulletins (TIBs), and dose reconstruction workbooks; however, items identified in this report may be applied to other facilities, especially facilities with similar source terms and exposure conditions. The review identifies a number of issues and discusses the degree to which the site profile fulfills the review objectives delineated in SC&A's site profile review procedure.

3.1 OBJECTIVES

SC&A reviewed the site profile with respect to the degree to which technically sound judgments or assumptions are employed. In addition, the review evaluates assumptions by NIOSH as to the degree that they are claimant favorable.

3.1.1 Objective 1: Completeness of Data Sources

SC&A reviewed the site profile with respect to Objective 1, which requires SC&A to identify principal sources of data and information that are applicable to the development of the site profile. The two elements examined under this objective include (1) determining if the site profile made use of available data considered relevant and significant to the dose reconstruction, and (2) investigating whether other relevant/significant sources are available, but were not used in the development of the site profile. For example, if data are available in site technical reports or other available site documents for particular processes, and if the TBD has not taken into consideration these data where it should have, this would constitute a completeness-of-data issue. The Oak Ridge Associated Universities Team (ORAUT) site profile document database, including the referenced sources in the TBD, was evaluated to determine the relevance of the data collected by NIOSH to the development of the site profile. Additionally, SC&A evaluated records publicly available relating to LBNL and information provided by site experts during the onsite visit.

3.1.2 Objective 2: Technical Accuracy

SC&A reviewed the site profile with respect to Objective 2, which requires SC&A to perform a critical assessment of the methods used in the site profile to develop technically defensible guidance or instruction, including evaluating field characterization data, source term data, technical reports, standards and guidance documents, and literature related to processes that occurred at LBNL. The goal of this objective is to first analyze the data according to sound scientific principles, and then to evaluate this information in the context of compensation. If, for example, SC&A found that the technical approach used by NIOSH was not scientifically sound or claimant favorable, this would constitute a technical accuracy issue.

3.1.3 Objective 3: Adequacy of Data

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

3.1.4 Objective 4: Consistency among Site Profiles

SC&A reviewed the site profile with respect to Objective 4, which requires SC&A to identify common elements within site profiles completed or reviewed to date, as appropriate. In order to accomplish this objective, the LBNL was compared with the Argonne National Laboratory-East (ANL-E) and Pinellas Plant site profiles. In particular, this dealt with how each site handled and is handling dose reconstruction for workers exposed to a wide range of radionuclides.

3.1.5 Objective 5: Regulatory Compliance

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

In order to place the above objectives into the proper context as they pertain to the site profile, it is important to briefly review key elements of the dose reconstruction process, as specified in 42 CFR 82. Federal regulations specify that a dose reconstruction can be broadly placed into one of three discrete categories. These three categories differ greatly in terms of their dependence on and the completeness of available dose data, as well as on the accuracy/uncertainty of data.

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

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

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

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

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

> *… estimates calculated using a substantial basis of fact and the application of science-based, logical assumptions to supplement or interpret the factual basis.* ***Claimants will in no case be harmed by any level of uncertainty involved in their claims, since assumptions applied by NIOSH will consistently give the benefit of the doubt to claimants.*** [Emphasis added.]

In order to achieve the five objectives described above, SC&A reviewed the TBD and its supplemental attachments, giving due consideration to the three categories of dose reconstructions that the site profiles are intended to support. The LBNL TBD generally provided adequate information for the dose reconstructor when adequate data were available to do that comprehensively. Exceptions are noted in the findings in Section 4.0.

- ORAUT-TKBS-0049, *Site Profile for the Lawrence Berkeley National Laboratory, Rev. 01* (ORAUT 2007), contains an Introduction that explains the purpose and the scope of the site profile. In addition, five other topics related to potential site radiological exposure are contained in this one site profile document. In most of the site profiles developed by NIOSH for DOE sites, these six distinct areas are contained in six individual documents. During the course of its review, SC&A was cognizant of the fact that the site profile is not required by the EEOICPA or by 42 CFR 82, which implements the statute. Site profiles were developed by NIOSH as a resource to the dose reconstructors for identifying site-specific practices, parameter values, and factors that are relevant to dose reconstruction. SC&A understands that site profiles are living documents that are revised, refined, and supplemented with TIBs, as required, to assist 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. The introduction in the single document helps in framing the scope of the site profile. As will be discussed later in this report, the "Purpose" (Section 1.1) and "Scope" (Section 1.2) sections are unusually brief and lack sufficient information to serve any useful purpose. The same applies for the "Site Description" (Section 2.0).

Section 3.0, "Occupational Medical Dose," provides an overview of the sources, types of exposure, and the frequency of exams that workers potentially received. Section 4.0, "Occupational Environmental Dose," provides background information and guidance to dose reconstructors for reconstructing the doses to unmonitored workers outside of the facilities at the site who may have been exposed to routine and episodic airborne emissions from these facilities.

Section 5.0, "Occupational Internal Dose," presents background information and guidance to dose reconstructors for deriving occupational internal doses to workers. Section 6.0, "Occupational External Dose," contains background information and guidance to dose reconstructors for deriving occupational external doses to workers.

After the Advisory Board and NIOSH have an opportunity to review this draft, SC&A plans to meet with the work group appointed by the Advisory Board and NIOSH to discuss our findings. Following these meetings, the draft may be revised, depending on direction we receive from the Advisory Board. We anticipate that, in accordance with the procedures followed during previous site profile reviews, the draft report and any subsequent revisions will be published on the NIOSH Web site. This last step in the review cycle completes SC&A's role in the review process, unless the Advisory Board requests SC&A to participate in additional discussions regarding the closeout of issues, or if NIOSH issues revisions to the TBD or additional TIBs, and the Advisory Board requests SC&A to review these documents.

Finally, it is important to note that SC&A's review of the TBD is not exhaustive. This document deals with a complex site and many documents, and SC&A used its judgment in selecting those issues that we believe are important with respect to dose reconstruction.

3.2 SITE PROFILE STRENGTHS

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

(1) The method used in Section 4.0, "Occupational Environmental Dose," for projecting environmental doses for the early years (prior to 1959) is consistent with the site development and appears to be both claimant favorable and plausible. The site profile fits the available data to a parabolic curve, which more nearly estimates the growth of site exposure sources than would a linear projection. The parabolic fit begins with a background value in 1942 and peaks with the value reported in 1959, the first year for which environmental data were available. The use of a linear growth would under-report doses in the late 1950s, and the use of the average dose from 1959 to 2004 would overestimate the doses in the 1940s.

(2) The use of "Attribution and Annotations" in the site profile document as a means of identifying and illuminating conclusions and recommendations contained in the site profile is helpful to the review. However, additional information is required for many of the items, since they are conclusions drawn by the site profile contributors, but give minimal justification and verification so that the conclusions of the authors can be validated.

(3) The level of information provided appears to be consistent with the supporting documents reviewed and the magnitude of the potential doses associated with LBNL operations. There are omissions in the TBD and additional information and considerations that should be included in revisions of the documents. These shortcomings are detailed in Section 4.0.

4.0 VERTICAL ISSUES

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

4.1 FINDING 1: INADEQUATE DOCUMENTATION OF HISTORICAL OPERATIONS AND SOURCES OF RADIOLOGICAL EXPOSURES

This review found that the site profile provides an inadequate overview of LBNL historical operations and the primary radiological exposure sources and conditions. The document lacks sufficient detail and analysis to provide comprehensive guidance to dose reconstructors. The period covered is large, as it is for several of the other DOE sites; however, the TBD failed to fully address the exposure implications of radiation sources to the degree necessary to allow a comprehensive assignment of historical doses, including missed doses.

The site profile document consists of one document that covers six areas; the Introduction, Site Description, Occupational Medical Dose, Occupational Environmental Dose, Occupational Internal Dose, and Occupational External Dose. SC&A's review found that each of these sections was deficient in its presentation of the information available on the subject for LBNL. Site profiles for other DOE sites, whose historical operations are equally or less complex and diverse, are more complete and informative to their intended audience than ORAUT-TKBS-0049. SC&A has made this determination through a review of historical records and interviews with site experts.

Specific operations and facilities are not discussed in sufficient detail. A prime example of the lack of significant detail and information is the coverage of the National Tritium Labeling Facility (NTLF). This facility operated for more than 19 years before closing in 2001, due to lack of funding. This facility provided tritium-labeled compounds for biological and medical research. There was considerable concern within the Berkeley community over the offsite exposure from this facility during its latter years of operation, to the point that the community hired an independent consultant to evaluate the safety of the facility. The NTLF handled large quantities of tritium in a great variety of chemical forms, including organically bound tritium (OBT) compounds (see Finding 3).

The site profile fails to discuss the accelerator program at LBNL. Since this is the major source of exposure to site workers, this represents a major exclusion. The site profile should discuss the historical development of accelerators at LBNL and provide a discussion of the various accelerators developed, and the potential for routine, unmonitored, and accidental exposure to workers from these sources.

4.2 FINDING 2: INSUFFICIENT INFORMATION FOR INTERNAL DOSE RECONSTRUCTION, ESPECIALLY DURING THE EARLY YEARS

There is insufficient information on bioassay monitoring before 1961, and the information on air sampling and building activities is not sufficient to calculate the workers' dose due to internal exposures. Workers were potentially exposed to a diversity of radionuclides at LBNL, as shown in Table 2-1 of the TBD, which lists the radionuclides of concern by building. Table 2-1 is incomplete in relation to the periods of time and quantities of radionuclides that were handled in the different areas. In addition, Table 2-1 gives no references for the source of information included in the table.

Table 2-2 lists the radionuclides that workers could have encountered in various areas and the maximum quantities that were present in some buildings, and occasionally, dates are indicated. However, many of the entries have no quantities specified. Table 5.8 in Section 5 lists the radionuclides and fractional activity by building, but the table is incomplete when compared to Tables 2-1 and 2-2 in terms of the buildings and radionuclides that were handled.

Table 5-8 was derived for calendar years 2001–2004, based primarily on airborne release data reported under the National Emissions Standards for Hazardous Air Pollutants (NESHAPs). No indication is given of the methodology used to convert air emissions to radionuclide inventory. Table 5-8 is of limited value because of its inability to relate exposures during the various periods of time to the 2001–2004 emissions.

Table 5-4 lists minimum detectable activities (MDAs) for in-vitro measurements, but is incomplete with regard to the totality of radionuclides that were handled at LBNL. Many radionuclides are presented with specific MDAs for the period after 1995, but the method of analysis is not specified. In-vitro detection limits for many radionuclides are not specified or assumed equal to ANSI HPS N13.30 values (Fe, Na, Ra, Th, U). The information on MDAs on the various periods is incomplete, posing a problem with the calculation of missed doses. Potential missed dose associated with inadequate bioassay techniques is not mentioned in this TBD. Discussions on the adequacy of monitoring techniques are missing, and the methods of analysis for many radionuclides are not specified; thus, the quality of the measurement techniques cannot be evaluated.

Gross alpha, beta, and gamma analyses are reported as being used for the entire site operation, including the present time. The TBD does not discuss the fact that many radionuclides present at LBNL would not have been detected by gross measurements, or at least detected with low recoveries and resulting high MDCs. In addition, the use of gross measurements results in an indeterminate MDC for a specific radionuclide. The potential missed dose associated with non-specific bioassay techniques should be further investigated to determine the impact on internal dose calculations. The TBD fails to provide guidance to the dose reconstructor on how to deal with mixtures of alpha or beta emitters for bioassay techniques that may analyze for multiple radionuclides using gross measurements.

4.3 FINDING 3: SPECIAL FORMS OF TRITIUM AND PLUTONIUM NOT ADDRESSED BY NIOSH

NIOSH fails to identify in the site profile that metal tritides and OBT are included in the materials used at the site. The site interviewees verified that tritium was used extensively at LBNL, in particular at the NTLF, Building 75. There is very little discussion about tritium exposures in the internal dose section (Section 5.0) of the site profile; however, during the interviews, it was stated several times by health physicists and another knowledgeable former worker that tritium at NTLF was the largest internal dose producer at the site after the opening of NTLF in 1979. It was also stated during the interviews that OBT and metal (at least uranium and titanium) tritides were handled at NTLF. Section 5.0 does not discuss specifically the frequency of bioassay sampling that was performed at NTLF, which is the most important parameter in performing adequate bioassay monitoring for tritium.

The lack of coverage in the site profile for NTLF tritium-related doses is a major weakness in this profile, especially when all interviewees discussing the NTLF pointed to it as the largest internal dose contributor on the site during its operation. NIOSH should include a more comprehensive discussion of the types of materials processed in the NTLF and the methods it will use to perform dose reconstruction for any exposures to the various forms of tritium used at the facility.

During the interviews, health physicists stated that it was possible that highly oxidized/high-fired forms of actinides were handled at the site. They stated that the most likely source of exposure to these forms would have been related to the production of sealed sources and targets that were made for use at LBNL and other national laboratories. A recent letter from the U.S. Department of Labor to claimants (dated February 22, 2008) has identified LBNL as one of the sites where NIOSH started using a new model for "Super S" (highly insoluble forms) plutonium in performing dose reconstructions. Therefore, it is possible that NIOSH is addressing this issue for plutonium exposures at LBNL; however, the site profile does not address high-fired forms of other actinides (thorium, uranium, etc.). NIOSH should update the site profile detailing how it will handle high-fired forms of actinides in dose reconstruction for this site.

4.4 FINDING 4: BIOASSAY DATA COMPLETENESS AND ADEQUACY HAVE NOT BEEN VERIFIED

During the site visit by SC&A, it was determined that the bioassay database does not contain all bioassay data for all workers. SC&A found bioassay data in old files during the records search, which LBNL dosimetry staff verified were not in the database; therefore, it appears the database may be incomplete. In addition, bioassay submittals were delinquent by at least 1 year in some file records. This delay could increase the minimum detectable doses significantly, especially for soluble and short effective half-life nuclides.

In Tables 5-1 through 5-5 of the TBD, NIOSH listed many in-vitro and in-vivo bioassay methods, along with information on frequency of sampling. Given the great number of radionuclides that could have been involved with internal exposures at LBNL, it is apparent that many of these are short-lived relative to the bioassay frequency. An example for this is the production and use of I-131, which has an approximately 8-day physical half-life. The in-vivo frequency for whole-body counts is shown as annual in Table 5-3. In-vivo counting for I-131 should be done within a few weeks after the possible exposure, due to the short half-life; therefore, an annual whole-body count would not detect an intake that occurred several months before the count. There are several other short-lived nuclides that LBNL handled (e.g., Na-24 with a half-life of 15 hours, In-112 with a half-life of 21 minutes, and Ba-127/ CS-127 with a half-life of 6 hours, among others), which would not be detected in most cases by an annual bioassay in most cases.

During the site records search, a list of personnel that were delinquent for turning in their required bioassay samples was found. Some of the samples were late by several months. NIOSH should determine if the late bioassay samples could diminish their usefulness for the purpose of reconstructing internal doses.

During the site interviews, it appeared that work conducted at the Donner Laboratory and other laboratories at the Berkeley campus was not monitored and/or controlled as stringently as at other LBNL facilities. NIOSH should investigate the possibility that internal dose information (bioassay and air sampling data) for the work at these laboratories is adequate to reconstruct doses at these locations.

4.5 FINDING 5: INSUFFICIENT JUSTIFICATION FOR SELECTION OF IREP ENERGY RANGE FRACTIONS FOR PHOTON EXPOSURES

In Table 6-2 of the TBD, beta and photon doses are assigned to energy ranges according to the radioactive materials used in individual buildings at LBNL. For Buildings 51 and 71, entitled Cyclotrons and Accelerators, a single photon energy distribution is given, and 10% of the measured dose is assigned to the 30–250 keV range and 90% assigned to >250 keV. It appears that this photon energy distribution is being applied to the entire history of accelerator use at LBNL. It is questionable that this energy distribution is appropriate in all situations and timeframes. For example, technicians who handled targets, ion sources, and internal components of accelerators would have been exposed to a very different spectrum than those only exposed to radiation transmitted and degraded by several feet of concrete or metal shielding. In the early years, it is much more likely that technicians and others would be exposed to low-energy emitters shortly after a machine was powered off or even during operation. This was presumably less likely as energies and risks grew larger and commensurate standards and protective practices evolved.

Regardless of the precise fraction that should be assigned, the choice of less than 100% to the 30–250 keV category should only be made where there is supporting evidence. As it stands, the selection of a 10% fraction is not claimant favorable and not buttressed by the inclusion of supporting evidence. Although the other buildings have been assigned factors greater than 10% for the more claimant favorable 30–250 keV photon energy range, the fact that the accelerator buildings have been assigned a single low factor creates doubt on the validity of the factors and the process by which the factors were determined for the remainder of the site. NIOSH should provide justification other than, "…it was done in a manner similar to the LLNL and LANL facilities" for the assignment of the fractional factors in Table 6.2 of the TBD.

4.6 FINDING 6: INSUFFICIENCY OF NEUTRON DOSIMETRY TREATMENT

4.6.1 NTA Film Energy Threshold Determination

As has been the case in a number of site profiles prepared by NIOSH, there is an inconsistent approach to the energy cutoff for the NTA neutron dosimeter. Callout "c." in Table 6.5 references NIOSH 2002 as listing the NTA lower energy threshold at 500 keV, yet attribution number 47 discusses 800 keV as the threshold, and this is used as the basis for this TBD. Other sources list 1,000 keV as the threshold for NTA response. The assumption that NTA film responds down to 500 keV is not justified by the technical data and is not claimant favorable. This issue is especially important, as the field to which the individual was exposed is usually poorly characterized and the neutron weighting factors are large and variable over the range of 0.1 to 2 MeV.

4.6.2 Failure to Adjust Recorded Doses to Correct for Lack of Response of NTA and CR-39 in the Intermediate and Thermal Neutron Energy Range

Table 6.6 of the TBD, "Adjustments to Recorded Dose," defines the corrections for photon and neutron dosimeters to adjust the measured quantity; however, no adjustment is indicated for the failure of NTA film to respond to intermediate energy neutrons. The priority should be to ascertain the neutron dose and then correct it for weighting factors, etc. As presented, a significant part of the spectrum is inappropriately monitored and uncorrected.

There is virtually no discussion of the potential for neutron fields throughout this historical facility. Given that LBNL was a world leader in accelerator development, and given the leading-edge high energies developed by the machines, it is likely that there was the potential for unanticipated radiation fields and possible neutron exposures across a range of energies, especially in the early decades. Some discussion of this is called for in the TBD.

The scale of the issue with regard to under-response of NTA to intermediate neutron energies is fully explored in the Los Alamos TBD. Although LANL and LBNL are quite different in terms of sources of neutrons, many of the same detection issues remain. One part of the LANL TBD expresses the issue well:

> *…6.2.3.6 Workplace Neutron Dosimeter Response*
> *The AEC held a series of Personnel Neutron Dosimetry Workshops to address problems experienced by its sites concerning accurate measurement of neutron dose. The first workshop was held September 23 and 24, 1969 (Vallario, Hankins, and Unruh 1969) with the stated concern: "... for intermediate energy (i.e., > 0.4 eV to < 700 keV) ... neutron sources, NTA personnel neutron dosimeters cannot be effectively used. This leaves a gap in the personnel dosimetry program which at many installations may be quite serious.…*

There is a remarkable silence as to thermal or slow neutron exposure in the site profile document. Only one mention of slow neutrons is made in the site profile document and that one is only made in passing (bold added for emphasis):

> *…Dose reconstructors should use the electroscope results in a qualitative manner because no data were found on the calibration or energy response of these devices; they should use the film or TLD results to estimate the actual exposure or the electroscope reading if no corresponding dosimeter reading exists.* ***The electroscope results include daily readings in tables captioned "dosimeter," "slow neutron," and "electroscope."*** *The three readings, which occurred on the same dates, were evidently used to measure exposure at the end of work shifts ….*

No other mention of slow or thermal neutrons is made. A search of the "O" drive revealed only a single document (referenced in the above paragraph) that mentioned slow or thermal neutrons. Clearly there was the potential for exposure to slow neutrons, as slow neutron electroscopes were in use in 1956 and readings were documented for several individuals. NIOSH should investigate the issue as part of a broader look at the intermediate and slow neutron exposure potential. If there was minimal opportunity for thermal neutron exposure, then the TBD should document this conclusion.

It is unclear from the TBD how and when albedo TLD results were merged with CR-39 results. The gap in neutron response from above the cadmium cutoff to the lower energy threshold for CR-39 (also not mentioned, but assumed to be around 150 keV) is not discussed. NIOSH should evaluate the neutron program and determine how missed intermediate energy neutron dose should be determined for this period, as well as intermediate and thermal energy neutrons for the NTA and pre-NTA years.

4.6.3 Selection of Minimum Detectable Dose for CR-39 Dosimeters

Table 6-1 of the TBD shows that the MDL for CR-39 is 10 mrem, with no attribution provided. The Los Alamos TBD shows an MDL for CR-39 of 20 mrem. The current commercial service available from Landauer, Inc., also shows an MDL of 20 mrem. It is likely that the minimum detectable level for CR-39 is higher than 10 and more likely around 20 mrem. This number is important and it is likely to be amplified to take account of missed dose not only due to exposure below the detection limit, but also to estimate dose due to lower energy neutrons that would have been missed entirely, due to the inability of CR39 to detect lower energy neutrons.

4.6.4 Use of Neutron-Gamma Ratios for Situations Where Neutron Data are Lacking: Seeming Inconsistency Between the Environmental and External Dose Sections

Table 4.1 of the Environmental Occupational Dose section (Section 4.0) of the TBD contains estimates of annual environmental dose throughout the history of the facility. The values provided are totals of neutron and photon exposure. The following footnote describes the assumption as to the proportion of neutron and gamma:

> *c. Energies are 30 to 250 keV for photons and 0.1 to 2 MeV for neutrons. Neutron component of dose is typically ≥70% of total….*

However, Note c. in Table 6-6 of the External Dose section of the TBD states that the ratio of neutron-to-photon dose should be assumed to be 0.73:

> *c. The NTA dosimeter (1941 to 1969) exhibited a lower energy threshold of approximately 500 keV (NIOSH 2002). The photon dose was measured adequately and all LBNL neutron dose was accompanied by a significant photon dose. For neutron dose received before 1969, the dose should be adjusted by using a neutron-to-photon ratio. The neutron exposure was determined with a neutron-to-photon ratio of 0.73 ±2.1 …. The geometric mean was 0.73, and the geometric standard deviation was 2.1…. The assumed upper 95th percentile was assumed to be 2.47….*

Thus, the Environmental Dose section utilizes a ≥70% factor and the External Dose section utilizes a 42% factor. This significant difference in the average site-wide neutron-to-photon ratio is surprising. It is possible that the environmental dose includes more sky shine and other factors. However, this issue needs to be addressed and the large difference explained.

This section on the determination of missed and missing neutron exposure needs a thorough review. Both the source terms and the dosimeter response specifications need to be addressed.

4.7 FINDING 7: FAILURE TO JUSTIFY THE SHALLOW DOSE-TO-DEEP DOSE ASSUMPTION

The TBD provides guidance on the dose to be assigned in the "early" years (pre-1979) for which there is no record of beta exposure. The Occupational Dose section suggests the following (pg. 39):

> *…There are no records of reporting beta exposure using film from before 1979. This is presumed to be because the radiation protection staff at the time felt that deep dose was controlling to meet regulatory limits (i.e., that the shallow dose could not exceed the deep dose by a high enough amount to come close to the higher regulatory limit). The radiation protection staff was aware of the need to monitor for nonpenetrating radiation and used a film badge containing filters (LRL 1958e). Inasmuch as the limit for WB (deep) dose was 5 rem/yr and for skin (shallow) dose was 15 rem/yr, it is reasonable to assume that the shallow dose could not exceed the deep dose by more than a factor of 3…. For cases where the shallow dose is important to reconstruction and is not reported, dose reconstructors should apply a factor of 3 to the WB dose to estimate the shallow dose...*

In the general case, the assumption of a factor of 3 for the ratio of shallow dose-to-deep dose is reasonable and claimant favorable. However, LBNL had a broad mandate and, as the site description states on page 8:

> *From the 1950s to the present, the laboratory has maintained its status as a major international center for physics research and has diversified its research program into almost every realm of scientific investigation.*

Table 2.1 of the LBNL TBD shows that for the year 1931, H-3, C-14, P-32, P-33, Sr-90, I-125, Th-232, and U-238 were handled in the Donner Laboratory. Likewise, in Buildings 55/56 in 1964, H-3, C-14, F-18, P-32, I-131, Sr-90, Xe-127, Nb-95, Ru-103, Gd-153, Tl-201, I-123, I-125, Sn-113, Tc-99m, Co-57, Cr-51, Nb-95, O-15, Cu-64, Ce-141, N-13, Sr-85, Sc-46, C-11, and Co-55 were used. There are many other examples in the table of a broad array of nuclides that were present at a given location. Unfortunately, in most cases, the site description does not provide sufficient detail as to the quantities, forms, and methods under which these materials were handled. What is known is that the levels of protection in the 1940s, 1950s, and 1960s were far from what would be considered good practice today.

There is no mention of head and eye dose or non-uniform whole-body irradiation in the site profile. Typically, workers handling beta emitters and those performing maintenance inside accelerators can be exposed to significant non-uniform fields. Likewise, there is no mention in the TBD of potential skin and clothing contamination and resultant exposure.

It is unclear from the TBD if workers were exposed to significant shallow dose with possibly little deep dose to be used as an indicator. Possible activities that may have been conducted include fume hood operations, maintenance of accelerators, ventilation and plumbing systems, waste disposal operations and spill cleanup. The lists of nuclides are extensive and include beta emitters, including some pure beta and low-energy x-ray emitters. For some personnel, the 3:1 ratio may not be claimant favorable. NIOSH needs to identify the workers who could have received exposure from these beta or low-energy x-ray emitters, or provide an alternative method of estimating the shallow dose in a claimant-favorable manner.

4.8 FINDING 8: UNCERTAINTY IN BETA-GAMMA DOSIMETER RESPONSE TO RADIATION TYPES AND ENERGIES

4.8.1 The Use of Early Electroscope Data Needs Greater Definition

Page 39 of The TBD Describes *The Use Of Electroscope Data*:

> *… LBNL began operations using dosimeter and processing technical support provided by the Metallurgical Laboratory at the University of Chicago. After 1952, LBNL operated its own fully functional personnel dosimetry program with in-house processing. Exposure data were recorded by film badges and thermoluminescent dosimeters (TLDs). Early exposure records also provided electroscope (or at times, electrometer or E was used) results, which supplemented the results measured by film. Dose reconstructors should use the electroscope results in a qualitative manner because no data were found on the calibration or energy response of these devices; they should use the film or TLD results to estimate the actual exposure or the electroscope reading if no corresponding dosimeter reading exists. The electroscope results include daily readings in tables captioned "dosimeter," "slow neutron," and "electroscope." The three readings, which occurred on the same dates, were evidently used to measure exposure at the end of work shifts …. There are data in worker records that show a comparison of the film dosimeter to electroscope records for the same*

> *interval; the data are similar and correlate, but they are not identical. This is probably due to a combination of differences in energy dependence, calibration techniques, where the dosimeters were worn in relation to each other, exposure geometry, etc.*

A search of the "O" drive found that, anecdotally at least, there were significant problems with electroscopes. A study performed November 23, 1953, by Jim Bennett (Bennett 1953) showed that readings from the three electroscopes tested were widely divergent from the film that was exposed with them. Two gave a 10% response compared with the film and the third was off scale. No details are provided as to the energy of the gamma source used for the exposure. However, the memo provides a cautionary statement as to using electroscope data even in a qualitative manner.

4.8.2 Dosimeter Response to Very High Energy Photons and Charged Particles

LBNL was a pioneer in the development of high energy physics and in the search for exotic particles. The film and electroscopes in use in the early decades will likely not have been calibrated for energies above 1 or 2 MeV. NIOSH should evaluate the dosimetry and potential for exposure to radiation at energies above that commonly produced by radioisotopes. The detectors will have responded to some degree, but the correction factor size and sign are unknown and not mentioned in the TBD. The response of the detector element or film, for example, will depend greatly on the composition of the holder and filters.

Among the questions that arise from the review for consideration by NIOSH include: What information is available as to fields of radiation surrounding the newly developed accelerators? Were there opportunities for individuals to be inadvertently (or intentionally) exposed to beams of high energy charged particles or photons? Was shielding sufficient to reduce effective energy levels to less than 1–2 MeV for practical purposes? Information needs to be provided by NIOSH relative to these questions.

4.9 FINDING 9: X-RAY EXPOSURES ARE UNCERTAIN

Table 3-1 of the TBD lists the entrance skin exposure (ESE) doses used for the PA chest exam. It states that until 1975, all dose estimates are defaulted as being what is provided in ORAUT-OTIB-0006 (ORAUT 2005a). There is no information identified as being available on x-ray equipment that was used prior to 1975. Depending on how one views this information, there is no indication that this default is claimant favorable for the years 1942 through 1975. NIOSH needs to better describe what measures were taken to determine what types of equipment were used. For example:

- Where did workers get exams between the years 1942–1975?
- Were medical records available, and do they indicate if x-rays were taken?
- Were workers sent to alternate locations for exams, and were those records researched?
- Did NIOSH research address the potential use of photofluorography (PFGs) to screen workers up through 1960?

The TBD should be expanded in its discussion of the medical dose to address the issues indicated in the above questions in order to be considered complete.

4.10 FINDING 10: UNCERTAINTY OF CALCULATING DOSES PRIOR TO 1961

There is no information on how NIOSH is planning to reconstruct doses before 1961.
In ORAUT-TKBS-0049 (ORAUT 2007):

- Table 5-1 lists the in vitro types of bioassay, the periods, and the frequencies of monitoring. It does not contain any information that might be applicable to calculate doses for exposures before 1961.
- Table 5-4 lists the MDA for various analysis results. The only pre-1961 information available is the MDA for gross alpha, and gross beta is for 1957–1961.
- Table 5-8 contains only one reference to exposures before 1961.
- Looking at the files for LBNL in NOCTS, 24 claimants received compensation. Those were probably the most exposed workers, and 18 of the 24 claimants started working before 1961. There is only one bioassay record before 1961; a uranium urinalysis done in 1958.
- Looking at the 99 claimant files for LBNL who did not receive compensation, 31 started working before 1961. There is only one bioassay record before 1961; a C-14 breath analysis performed after an incident in 1959.

There is insufficient information related to bioassay monitoring before 1961 in the TBD.

4.11 FINDING 11: INADEQUACY OF BIOASSAY ANALYSES PRESENTATION

There was a diversity of radionuclides at LBNL. The Occupational Internal Dose section of ORAUT-TKBS-0049 specifies that, "from 1960 to 1996, both in vitro and in vivo monitoring records and associated interpretations exist." In Table 5-4, MDAs are listed for gross alpha for the isotopes of thorium, plutonium, curium, actinium, and neptunium. The same method and MDA is listed for Cf-252 from 1965–1995. There is a remark specifying that, "method descriptions note that uranium, radium, and polonium are not detected by this method (Author unknown, no date)." The MDA for U is specified for 1961–1988. In this table, MDAs are also listed for gross beta, Sr/Y-90, Sr-89, Ba/La-140, Ce/Pr-144, and fission products. There is an MDA listed for S-35 for 1962–1992, and one for rare earths (primarily Pm-147) just for 1961.

Table 5-5 specifies in-vivo detection limits for gamma-emitting radionuclides 50 keV–2 MeV (including thyroid counts for I-131, I-123), Be-7, Na-22/24, Mn-54, Ni-57/63, Fe-55/59, Co-57/58/60 and Zn-65 for 1960–1996. For the same period of time, MDA for gamma-emitting radionuclides <50 keV (e.g., I-125) are also specified.

Table 5-8, "Radionuclides and fraction activity by facility," is incomplete and difficult to use in relation to discrimination between exposures during the various periods of time the rooms were used in the installation.

- In NOCTS, the files of the 24 claimants from LBNL that received compensation show that 22 started working before 1969. No in-vivo monitoring was recorded in the period 1960–1969.

- Of the 99 claimants for LBNL in NOCTS who did not receive compensation, 59 started working before 1969. No in-vivo monitoring was recorded in the period 1960–1969.

- A document referenced in ORAUT-TKBS-0049 entitled, "Individual Bioassay Reports for Employees Beginning Last Name with A – 1965–1990," reports bioassay done from 1960–1990. Only gross alpha is reported until 1968, and gross alpha, gross beta, and gamma are reported in 1969. The first WBC is reported in 1970.

- The document SRDB 21986 referenced in ORAUT-TKBS-0049 titled, "Terminated Bioassay Results of Employees with Last Name Beginning with A, 1961–1983," lists bioassay monitoring of 106 employees, with last name beginning with A and B. Only gross alpha is reported from 1960–1966, with one exception of a WB counting in 1965. In 1967, gross alpha and beta are reported and several people involved in accidents were monitored in the WB counter. In 1968, gross alpha and beta are reported, plus in two cases, specific monitoring for actinides for Cf-252 and Am-241. In 1969, gross alpha, gross beta, and gamma urine counting are reported, plus a limited number of specific radionuclide analyses and WBCs.

From these four lists of bioassay results, it is possible to conclude that the bioassay monitoring relied largely on measurements of gross alpha until 1964, and from 1964–1967 on gross alpha, beta, and gamma. Table 5-4 from ORAUT-TKBS-0049 does not give the MDA for gamma in-vitro monitoring before 1969, although this kind of monitoring is reported. WBC results are reported after 1965 for all related to incidents.

Tables 5-1, 5-2, and 5-4 describing in-vitro bioassay programs, methods, and MDAs are incomplete and do not give enough information on internal dose calculations for LBNL employees. Table 5-8 is also incomplete and difficult to use, in relation to discrimination between exposures during the various periods of time and the rooms used in the installation.

4.12 FINDING 12: FAILURE TO PROVIDE SUFFICIENT GUIDANCE FOR UNMONITORED WORKERS

The TBD fails to provide guidance on how to calculate doses to workers without a complete description of the monitoring programs (Table 5-1), and on how to assign monitoring results to specific radionuclides and compounds. The TBD admits that, for many of the radionuclides, there is no specific information on the compounds with which they may have been associated.

Insufficient guidance is provided on estimating internal doses for unmonitored workers. The information on bioassay programs is incomplete, as well as the list of radionuclides and compounds handled at the facility, in the different times and locations. The TBD suggests that unmonitored workers should be assessed using coworker data and the tolerance levels, if there is evidence that they worked with uncontained radioactive materials; otherwise, environmental data should be used. This suggestion cannot be followed using the information available in the TBD.

NIOSH should revise the site profile document to provide information sufficient for proper dose reconstruction, particularly for unmonitored workers.

4.13 FINDING 13: INADEQUATE COVERAGE OF OCCUPATIONAL ENVIRONMENTAL DOSE

Section 4.0 of ORAUT-TKBS-0049, "Occupation Environmental Dose," is incomplete and should be revised to provide a more comprehensive description of the historical environmental dose to workers at LBNL. The deficiencies and omissions are such that inadequate guidance is provided for dose reconstructors.

NIOSH uses the data reported from the site environmental reports, for the years they are available (1959–2004), to generate Table 4-1 providing the external gamma and neutron doses for the site for the operational years. For 2 years, 2002 and 2004, the data were reported as "not detected," and NIOSH provided estimates by averaging the 5 previous years' results. In addition, no reports were available for the years 1942 through 1958. NIOSH used a parabolic curve method to estimate the gamma and neutron doses for these years. Both of the estimating methods seem appropriate, given the time periods, rate of growth of the exposure sources, and the resulting estimates comparison.

NIOSH assumes that the gamma and neutron environmental exposure is primarily from accelerators, and thus using the maximum measured value from the onsite and fence-line monitors for a given year would be claimant favorable. NIOSH fails to discuss the possible exposure to unmonitored workers from irradiators. In particular, the Co-60 irradiator housed in Building 74 may have been capable of higher doses at locations at distances less than those to the site perimeter or onsite monitoring locations (LBNL 1995a).

Table 4-2, "Maximum site-wide annual median intakes (Bq/yr) via inhalation," contains the NIOSH best estimates of annual intakes. Except for tritium and C-14, the values in the table are based on gross alpha and beta measured values from the site environmental program. The site profile states:

> *LBNL attributes gross alpha results to ^{232}Th and gross beta results to ^{90}Sr for the purposes of dose calculation; these assumptions should be made.*

The LBNL 1994 Environmental Report (LBNL 1995a) states:

> *Throughout this report, unidentified radionuclides are assumed to be ^{232}Th if they are alpha-emitting material or ^{90}Sr if they are beta emitting material. This is a conservative approach because these assigned radionuclides represent the most restrictive alpha and beta emitters listed in DOE Order 5400.5* [DOE 1990].

While this may be a conservative assumption relative to the effective dose equivalent, this may not be claimant favorable for specific organ doses. For example, for exposure to I-131, where the committed dose equivalent per unit intake for the thyroid is almost two orders of magnitude greater than for Sr-90, the dose to the thyroid would be grossly underestimated. Given the wide range of radioisotopes used at LBNL, NIOSH should present a more claimant-favorable approach to dose reconstruction for radionuclides whose intakes were determined from gross alpha and beta measurements.

4.14 SECONDARY ISSUES

In addition to the above findings, there were additional concerns with the TBD. While these secondary issues do not rise to the level of a finding, they should be addressed by NIOSH to achieve a comprehensive site profile document.

Secondary Issue 1: The Site Profile does Not Address LBNL Staff Assigned to the Nevada Test Site or the Significance of Its Employees Working at Other DOE/AWE Sites

During the site visit, a file was identified that contained data for an LRL-Nevada contingent assigned to the Nevada Test Site. One of the accelerator scientists interviewed stated he had worked at several other national accelerator sites (Fermi Lab, SLAC National Accelerator Site, etc.) while employed at LBNL and never received dose reports from those sites. NIOSH should determine if all DOE/AWE dosimetry data for each LBNL employee that worked at other sites can be retrieved and merged into the dosimetry records used by dose reconstructors.

Secondary Issue 2: More Information Needed for Internal Dose Assignment for Short-Lived Radionuclides

It is apparent from Table 2-1, "Area information and parameters," that workers were exposed to short-lived nuclides and nuclides with little or no gamma emissions whose burdens from intakes would be difficult to detect with an annual WBC. For these radionuclides, very timely urine bioassay or representative air sampling would be needed if there was potential for intakes. NIOSH offers no guidance for assigning doses for these short-lived radionuclides.

Secondary Issue 3: Lack of Discussion of Radiological Incidents

There is no discussion on radiological incidents, although records of several accidents and spills were discovered during the site visit. These include the vaporization of a Cm-244 target, which went into the ventilation system at HILAC. It does appear that for major incidents, the exposure for the persons involved was documented in their personal exposure data. However, there is concern that for small incidents (such as a skin contamination events), the exposure for the workers involved would be recorded in their personal data file and not in their exposure folder.

Secondary Issue 4: Need to Provide Information on Metallurgical Laboratory

The TBD mentions the fact that the Metallurgical Laboratory at the University of Chicago provided dosimeter processing and technical support until 1952. Section 6 of the TBD states:

> *LBNL began operations using dosimeter and processing technical support provided by the Metallurgical Laboratory at the University of Chicago. After 1952, LBNL operated its own fully functional personnel dosimetry program with in-house processing.*

No further mention is made of this in the site profile. NIOSH should provide information as to how the work was performed, calibration methods, and differences observed in measured exposures once LBNL began their own dosimetry operations.

Secondary Issue 5: Lack of Information on Isotopes, Facilities, and Handling Methods

A wide variety of activities were apparently conducted to discover and understand new elements and isotopes. As quoted in the Internal Dose section, Section 5 of the TBD:

> *The Laboratory's work was devoted to fundamental research on new elements, new isotopes, or properties of already known isotopes (Thaxter 1958).*

Other than a very broad list of the isotopes that were handled, there is no information as to the facilities and methods used for handling. For example, there is no information on shielding utilized, if remote handling tools were used, and the processes involved in the use of isotopes. In addition, some indication of specific activity, as well as overall activity, is needed to determine whether shallow and extremity dose issues arose. Given the large number of laboratories and isotopes handled, it is recognized that this is a complex task, but additional information and discussion in the TBD are needed.

Secondary Issue 6: Extremity Dosimetry Needs Revisiting

On page 40, the site profile describes the limited information available regarding extremity monitoring and notes the lack of mention of wrist badges:

> *…There is limited information about the use of extremity dosimeters before 1982. It appears that X-ray film was used as finger rings; there is no reference to wrist dosimeters (as were used at LANL or Oak Ridge National Laboratory) …*

There is some discussion of "palm film" use that appears in documents on the "O" drive. Two reports, Ref IDs 21503 (Unknown Author 1978) and 20881 (Unknown Author 1979), give palm film results for 1972–1979 and 1979, respectively. These reports were added to the database in January 2006, and should have been available during the period that the site profile was being prepared. NIOSH should revisit the extremity dosimetry issue and ascertain whether additional relevant information is available that was overlooked.

Secondary Issue 7: Lack of Sufficient Information for External Dose Evaluation

There is a litany of issues that are not addressed in the external dose review. The following list contains items that are needed in order to fully understand the capabilities of the dosimetry system. Many of these items are critical, as they determine whether or not particular radiations and energies were even detected by the dosimeter. In addition, the dosimetry program underwent several changes over the course of time. The dates of these changes and the data for each period are needed.

Dosimetry Program Specifics

- Film emulsion type and wrapper specifications
- Holder specifications
- Angular response to various radiation types
- Wear location on the body (including under or over protective clothing)
- Calibration source, protocol
- Processing methods for film, including methods for calibrating and controlling individual batches of processed film
- Quality Control and Quality Assurance programs
- Algorithm for each badge type, radiation type, and combinations of radiations
- Method of handing control, blank, and background badges
- Badge storage locations
- Limit of detection (LOD) broken down for beta, x-ray, and gamma radiations
- Chain of custody procedures
- Handling of visitors and subcontractors

Site Description

- Maps and figures of the site, so that assumptions regarding source terms, for example, can be placed in context.
- Design criteria and how they evolved over time. For example, what was the acceptable shielded dose rate in both continuously and occasionally occupied restricted and public spaces?
- Surveys and typical dose rates for all facilities and timeframes across the site.

Secondary Issue 8: Overuse of Generalizations and Assumptions

There are a number of places in the TBD where broad site-wide and time-encompassing correction factors or energy group breakdowns are made.

The shallow-to-deep dose, the selection of IREP photon energy fractions, and the neutron-to-gamma dose ratios are examples of this tendency to generalize across broad disciplines, radiation source terms, and timeframes. NIOSH needs to review all the situations where broad brush factors such as these have been proposed and determine appropriate sub-divisions and break out specific factors based on location, timeframe, job function, etc.

An example of a broad generalization is in Table 6-5, which includes the following paragraph regarding monitored/unmonitored individuals (bold added for emphasis):

> *From review of LBNL documents, it is not clear if all employees were continuously monitored. However, the monitoring records appear to be complete.* ***It can be assumed if no monitoring records are included in an employee's file that the individual was not monitored****.*

This generalization is not reasonable nor claimant favorable. It suggests that over the last 67 years, monitoring files have never been mislaid or lost at LBNL. In addition, it makes the sweeping assumption that chain of custody was always perfect and that, for example, a measurement was never inadvertently placed in a record for someone with a similar name or identification number. NIOSH should adjust instructions to ensure that dose reconstructors take due care to research the individual's record in a variety of ways to ensure that sweeping assumptions are not used.

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

The SC&A procedures call for a "vertical" assessment of a site profile for purposes of evaluation of 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.

5.1 SATISFYING THE FIVE OBJECTIVES

The SC&A review procedures, as approved by the Advisory Board, require that each site profile be evaluated against five measures of adequacy—completeness of data sources, technical accuracy, adequacy of data, site profile consistency, and regulatory compliance. The SC&A review found that the NIOSH site profile for LBNL falls short in fully characterizing a number of key underlying issues that are fundamental to guiding dose reconstruction. Section 6.0 summarizes the key issues. Detailed evaluation of these issues is found in Section 4.0 of this report, "Vertical Issues."

5.1.1 Objective 1: Completeness of Data Sources

The breadth of data sources used as a basis for the LBNL site profile is evident in the number of reports available in the Site Profile Research Database, as well as the number of reports cited in the site profile references. ORAUT's use of the available sources indicates an understanding of site operations, radionuclide usage, and personnel monitoring data. However, as at most of the DOE sites, there is a lack of data for the early years of operation.

In Table 2-1 of the TBD, radionuclides are identified by their usage in site buildings; however, no source term data are included. It is unclear from this table and site profile text the amount of the individual radionuclides and the usage parameters that would assist in evaluation of the exposure parameters for the nuclides.

For time periods prior to 1959, there are virtually no data characterizing the external radiation fields outdoors. Procedures for estimating these missing data appear to be appropriately applied and claimant favorable; however, the degree to which these estimates conform to the actual radiation data is unknown.

5.1.2 Objective 2: Technical Accuracy

In general, the TBD for LBNL favorably reflects the depth of knowledge and technical understanding of the various authors and experts who developed the documents. The analyses and recommendations are generally consistent with NIOSH guidance and the available data from the site. Some exceptions are noted below.

The uncertainty in the values of the minimum decision levels or minimum detectable concentrations (MDC) for bioassay samples has not been adequately discussed in the LBNL site profile. This is exacerbated by the fact that a large number of radionuclides were present at the site and gross analyses were performed on the bioassay samples. This is a major concern, since the uncertainty associated with these parameters may have a significant impact on the estimate of missed dose.

The lack of information or contradictory information on the radionuclides, compounds, and quantities that were handled, during different time periods, among the rooms and buildings are a concern to the technical accuracy of dose reconstruction. The lack of knowledge concerning the methods of analysis of specific radionuclides presents a significant uncertainty to the estimation of doses. The uncertainty in the values of the MDAs of many specific methods is problematic in terms of accuracy of the dose calculations and missed doses. In addition, for bioassay results relying on gross alpha, beta, and gamma analyses and the lack of information on chemical recovery for specific radionuclides, on the ability to detect radionuclides in bioassay samples, on interferences from other radionuclides, and on the chemical solubility contribute to the uncertainty of dose reconstruction.

5.1.3 Objective 3: Adequacy of Data

On the whole, the TBD addresses the data necessary for assignment of occupational dose, including missed and unmonitored dose, for LBNL. However, the presentation and discussion of the data are not adequate to calculate internal doses, and are not always addressed in a succinct and easily understandable manner.

5.1.4 Objective 4: Consistency among Site Profiles

SC&A compared and contrasted the methodologies to determine external, internal, medical, and environmental dose used in the LBNL Site Profile with other site profiles reviewed to date. These comparisons focused on the methodologies and assumptions associated with dose assessments and the derivation of values used to obtain a POC for individual claimants. Specifically, we compared the LBNL Site Profile to those for ANL-E and the Pinellas Plant. SC&A found a consistent application of NIOSH guidance and claimant-favorable assumptions at the sites, but found the LBNL site profile deficient in its presentation of the material necessary to verify the approaches taken.

5.1.5 Objective 5: Regulatory Compliance

SC&A reviewed the site profile with respect to Objective 5, which requires SC&A to evaluate the degree to which the site profile complies with stated policy and directives contained in 42 CFR 82. In addition, SC&A evaluated the TBD for adherence to general quality assurance policies and procedures utilized for the performance of dose reconstructions. Section 6 addresses this topic.

6.0 USABILITY OF SITE PROFILE FOR INTENDED PURPOSE

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

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

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

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

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

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

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

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

6.1 AMBIGUOUS DOSE RECONSTRUCTION DIRECTION

It is not clear from the Internal Dosimetry TBD (ORAUT-TKBS-0049) how dose estimation would be performed for workers who were not classified as radiation workers and who had access to LBNL radiological operations. Guidance is provided in this TBD with respect to missed dose calculations for unmonitored workers; however, the guidance is not adequately justified.

It is not clear from the Occupational Internal Dose section, Section 5 of the TBD, how dose estimation would be performed, with the incomplete, and many times contradictory, information that was given.

6.2 INCONSISTENCIES AND EDITORIAL ERRORS IN THE SITE PROFILES

Table 4-1 of the site profile contains an error in the final "Dose" entry. The dose for 2004 should be 2.41 mrem/yr, as opposed to 0.28, as indicated in the table.

Table 6-6 of the TBD contains erroneous citations (see Finding 6).

- The Attribution erroneously refers to annotation/attribution [52]. The correct attribution/attribution is presumably [47]. The notes are shown below:

  [52] Thomas, Bill R. ORAU Team, Task 3. May 1, 2006. Mr. Thomas reviewed the results provided in the NOCTS database to identify the frequency that dosimeters were exchanged. Design and type of film was described in the Argonne East TBD (ORAUT, 2006). Mr. Joe Guido, ORAU Task 5, June 5, 2006 confirmed that film badges were used through 1981 by reviewing claims in the NOCTS database.

- The Attribution also erroneously refers to annotation/attribution [54]. Again, the correct annotation/attribution is presumably [47]:

  [54] Thomas, Bill R. ORAU Team, Task 3. May 1, 2006. Mr. Thomas reviewed the results provided in the NOCTS database to identify the frequency that dosimeters were exchanged. The MDL was equivalent to that of the LLNL and LANL programs.

- Note c. describes the lower energy threshold as "approximately 500 keV (NIOSH 2002)." Yet annotation/attribution [47] says that the threshold is 800 keV.

  [47] Smith, Matthew H. ORAU Team. May 22, 2006. Mr. Smith and Mr. Thomas discussed the limited response of NTA film to neutrons with an energy below 800 keV. There were no documented studies of the poor response provided by LBNL. Mr. Smith suggested a response similar to that selected in the Hanford TBD (ORAUT, 2004) and information derived for the Rocky Flats Plant in OTIB-0027 (ORAUT, 2005c). It was necessary to establish a neutron to photon ratio in order to modify the NTA dosimeter results. For operations handling transuranics including plutonium, the neutron to photon ratio was judged to be similar to Hanford plutonium operations with a geometric mean of 0.73, GSD 2.1, and upper 95% 2.47 (ORAUT, 2004).

The Occupational Internal Dose section of ORAUT-TKBS-0049 specifies that "from 1960 to 1996, both in vitro and in vivo monitoring records and associated interpretations exist." However, Table 5-1, "In vitro Internal Dose Control Program," only includes the years of 1961, 1962, 1974, 1975, and 1995-present.

6.3 UNRESOLVED POLICY OR GENERIC TECHNICAL ISSUES

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

(1) Resolution is required on the availability of early records.

(2) Direction on the applicability of the TBD to individual dose reconstructions is absent.

(3) The method for dose assignment for alpha-emitting radionuclides, when only gross analyses were performed on bioassay samples, requires definition.

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

(5) The significance of various exposure pathways and the assumptions made that influence dose contributions need to be considered (most notably) for solubility and ingestion.

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

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

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

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

7.0 REFERENCES

42 CFR 82, 2002. *Methods for Radiation Dose Reconstruction Under the Energy Employees Occupational Illness Compensation Program,* of the *Code of Federal Regulation.*

Author unknown, no date, untitled document describing bioassay program. [SRDB Ref ID: 21251].

Bennett, J., 1953. Memorandum on "Film Badge Testing," Lawrence Berkeley Laboratory, Berkeley, California. December 2.

DOE (U.S. Department of Energy) 1990 (amended 1993). *Radiation Protection of the Public and the Environment*, DOE Order 5400.5.

LBL (Lawrence Berkeley Laboratory) 1965–1990, collection of employee bioassay records, University of California, Berkeley, California. [SRDB Ref ID: 21985, 21986].

LBNL (Lawrence Berkeley National Laboratory) 1995a. *1994 Site Environmental Report*, LBL-27170 (1995 rev.), University of California, Berkeley, California, May. [SRDB Ref ID: 6448].

LRL (Lawrence Radiation Laboratory), 1958e, "General Radiation Safety Practices (1957)," memorandum from Health Physics Department, UCRL, University of California, Berkeley, California, November. [SRDB Ref ID: 21745].

NIOSH (National Institute for Occupational Safety and Health), 2002. *External Dose Reconstruction Implementation Guideline*, OCAS-IG-001, Rev. 1, Office of Compensation Analysis and Support, Cincinnati, Ohio, August.

ORAUT (Oak Ridge Associated Universities Team) 2004. *Technical Basis Document for the Hanford Site – Occupational External Dosimetry*, ORAUT-TKBS-0006-6, Rev. 01, Cincinnati, Ohio. January 9, 2004.

ORAUT (Oak Ridge Associated Universities Team) 2005a. *Dose Reconstruction from Occupationally Related Diagnostic X-Ray Procedures*, ORAUT-OTIB-0006, Rev. 03 PC-1. Cincinnati, Ohio. December 21, 2005.

ORAUT (Oak Ridge Associated Universities Team) 2005c. *Interpretation of Dosimetry Data for Assignment of Shallow Dose*, ORAUT-OTIB-0017, Rev. 00. Cincinnati, Ohio. January 11, 2005.

ORAUT (Oak Ridge Associated Universities Team) 2007. *Site Profile for the Lawrence Berkeley National Laboratory,* ORAUT-TKBS-0049, Rev. 1. Cincinnati, Ohio. April 2, 2007.

SC&A 2004. *SC&A Standard Operating Procedure for Performing Site Profile Reviews*, Rev. 0. S. Cohen & Associates, McLean, Virginia. March 18, 2004.

Thaxter, M. D., 1958. "Protection Factors for Respirators, Action Levels for Respirator Use," Letter from M.D. Thaxter (LBNL) to D. Ross (U. S. Atomic Energy Commission), August 28. [SRDB Ref ID: 21995]

Unknown author, 1978. *Palm Film Folder Extremity Dosimeter Results by Name,* Lawrence Berkeley National Laboratory, Berkeley, California. [SRDB Ref ID: 21503]

Unknown author, 1979. *Palm Film Report 1979,* Lawrence Berkeley National Laboratory, Berkeley, California. [SRDB Ref ID: 20881].

Vallario, E.J., D.E. Hankins, and C.M. Unruh, 1969. *AEC Workshop on Personnel Neutron Dosimetry, September 23 to 24, 1969*, BNWL-1340, Battelle Memorial Institute, Pacific Northwest Laboratory, Richland, Washington. [SRDB Ref ID: 11096].

ATTACHMENT 1: TECHNICAL DOCUMENTS CONSIDERED DURING THE REVIEW

Technical Basis Document

ORAUT-TKBS-0049, *Site Profile for the Lawrence Berkeley National Laboratory, Rev. 01* (ORAUT 2007)

Technical Support Documents

NIOSH (National Institute for Occupational Safety and Health) 2002. External Dose Reconstruction Implementation Guideline, OCAS-IG-001, Rev. 1, Office of Compensation Analysis and Support, Cincinnati, Ohio.

ORAUT-OTIB-0002, Rev. 01 PC-2, 2004. *Technical Information Bulletin, Maximum Internal Dose Estimates for Certain DOE Complex Claims*, Oak Ridge Associated Universities, Cincinnati, Ohio. May 7, 2004.

ORAUT-OTIB-0006, Rev. 03 PC-1, 2005. *Dose Reconstruction from Occupationally Related Diagnostic X-Ray Procedures*, Oak Ridge Associated Universities, Cincinnati, Ohio. December 21.

ORAUT-OTIB-0017, Rev. 00, 2005. *Interpretation of Dosimetry Data for Assignment of Shallow Dose*. Oak Ridge Associated Universities, Cincinnati, Ohio. January11.

ORAUT-TKBS-0029-1, 2005. *Technical Basis Document for Pinellas Plant – Introduction, Rev. 00*. Oak Ridge Associated Universities, Cincinnati, Ohio.

ORAUT-TKBS-0029-2, 2005. *Technical Basis Document for Pinellas Plant – Site Description, Rev. 00*. Oak Ridge Associated Universities, Cincinnati, Ohio.

ORAUT-TKBS-0029-3, 2006. *Technical Basis Document for Pinellas Plant – Occupational Medical Dose, Rev. 00 PC-1*. Oak Ridge Associated Universities, Cincinnati, Ohio.

ORAUT-TKBS-0029-4, 2005. *Technical Basis Document for Pinellas Plant – Occupational Environmental Dose, Rev. 00*. Oak Ridge Associated Universities, Cincinnati, Ohio.

ORAUT-TKBS-0029-5, 2005. *Technical Basis Document for Pinellas Plant – Occupational Internal Dose, Rev. 00*. Oak Ridge Associated Universities, Cincinnati, Ohio.

ORAUT-TKBS-0029-6, 2005. *Technical Basis Document for Pinellas Plant – Occupational External Dosimetry, Rev. 00*. Oak Ridge Associated Universities, Cincinnati, Ohio.

ORAUT-TKBS-0036-1, 2005. *Argonne National Laboratory - East – Introduction, Rev. 00*. Oak Ridge Associated Universities, Cincinnati, Ohio.

ORAUT-TKBS-0036-2, 2006. *Argonne National Laboratory – East – Site Description, Rev. 00 PC-1*. Oak Ridge Associated Universities, Cincinnati, Ohio.

ORAUT-TKBS-0036-3, 2006. *Argonne National Laboratory – East – Occupational Medical Dose, Rev. 01 PC-1*. Oak Ridge Associated Universities, Cincinnati, Ohio.

ORAUT-TKBS-0036-4, 2006. *Argonne National Laboratory – East – Occupational Environmental Dose, Rev. 00*. Oak Ridge Associated Universities, Cincinnati, Ohio.

ORAUT-TKBS-0036-5, 2006. *Argonne National Laboratory – East – Occupational Internal Dose, Rev 00*. Oak Ridge Associated Universities, Cincinnati, Ohio.

ORAUT-TKBS-0036-6, 2006. *Argonne National Laboratory – East – Occupational External Dosimetry, Rev. 00*. Oak Ridge Associated Universities, Cincinnati, Ohio.

ATTACHMENT 2: MASTER INTERVIEW SUMMARY

INTRODUCTION

As a technical support contractor to the Advisory Board on Radiation and Worker Health (Advisory Board), SC&A has been tasked with reviewing NIOSH's Lawrence Berkeley National Laboratory (LBNL) site profile. 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 was to hear first-hand accounts of past radiological control and personnel monitoring practices, and to better understand how operations and safety programs were implemented at the site over time. Interviewees were identified through available site reports, public meeting transcripts, local advocates, and other interviewees. This report summarizes the results of those interviews that were reviewed and accepted by the interviewees.

A team of SC&A interviewers, William James, Kathryn Robertson-DeMers, and Abe Zeitoun, conducted interviews at LBNL in Berkeley, California, between May 11 and May 15, 2009. One participant was interviewed by telephone on July 31, 2009. A total of 31 site experts participated in these interviews. However, due to a limited response to SC&A's request for participants' review of interview summaries, only 14 interviewee statements are included in this master summary.

The workers whose interviews are summarized below represent the time period from 1955 through the present (2009). Their work took them to the Bevatron, HILAC, SuperHILAC, Advanced Light Source (ALS), National Tritium Labeling Facility (NTLF), accelerators, hot cells, medical facilities, Donner Laboratory, Calvin Laboratory, and other research labs on campus and on the hill. Interviewees participated in research, production, medical services, radiation protection, dosimetry, environmental monitoring, maintenance, and administrative activities. Some participants have assisted other workers with medical issues, claims, and/or petitions. The worker categories represented by the interviewees include the following:

- Administrative Staff
- Dosimetry
- Environmental Protection
- Health Physics/Radiation Protection
- Industrial Hygiene
- Laboratory Directors Office
- Maintenance
- Medical Services
- Radiological Control and Monitoring Operations
- Scientists/Physicists
- X-ray Safety

SC&A explained that the interviews were being conducted on behalf of the Advisory Board as part of their review of NIOSH's LBNL site profile report. Participants were told that the interviews were unclassified, and that they should not disclose any classified information. Summaries from each interview set were prepared and provided to the interviewees for review.

Approximately 55% of participants did not respond to the request for review; the information obtained from interviews that were not validated by participants has been withheld from this master summary.

The information provided by the workers and site experts is invaluable in helping SC&A to better understand the operations at the LBNL. 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 Advisory Board and other interested parties information acquired by SC&A during these interviews. Comments are included in brackets where SC&A has provided clarification on a statement made by an interviewee.

Information provided by the interviewees was based entirely on their personal experience at LBNL. It is recognized that 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 have been consolidated into this single summary document. The information has been categorized into topical areas related to research and production operations, maintenance, dosimetry, radiological controls and monitoring, incidents and accidents, medical services, radiological records, environmental monitoring, 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 LBNL site profile.

RESEARCH AND PRODUCTION OPERATIONS

The interviewees, collectively, provided their characterization of radiation related work in various onsite facilities, as follows.

The primary radiation areas were in Buildings 4, 5, 6, 7, 14, 16, 70, 70A, and 75. There are detectable radiation levels around the accelerators. Buildings 1, 3, and 4 (Actinide Chemistry) have radioactive materials. In the case of Building 4, the material is in the duct system and sewer lines. Areas that have or had radioactive material or radiation-producing devices include the Advanced Light Source (ALS), the 88" Cyclotron, the Laser Wakefield Facility (Building 71), Medical Cyclotrons, radiographic testing x-ray equipment (Building 27), electron microscopes, and Van de Graaff accelerators (basement of Building 58 and Building 62). The hottest jobs onsite were target handling at the 88" Cyclotron, target handling at the 184" Cyclotron, and the tritium facility.

[There were several accelerator facilities at LBNL.] The Bevatron was used for physics experiments. It used sealed radioactive targets to avoid any radioactive contamination. The HILAC was a linear accelerator that beamed the lighter elements up to Ar. During [the 1970s], there was a lot of development work with the Bevalac, including upgrades and modifications. The HILAC was renamed the SuperHILAC and was connected to the Bevatron [in the late 1970s]. At that point, there was a beam line across the laboratory. The SuperHILAC had the ability to beam heavy ions up to uranium. The ALS was housed in Building 6. While the old accelerator was torn out, the walls that housed the old accelerator were not removed.

Non-traditional forms of radiation [at LBNL] include protons, muons, and heavy ions. Heavy ions are used for intentional exposure of patients. There is some activation of components [at the accelerators], including W-181, Co-57, Na-22, Sc, Re, Os, etc. Airborne activation was removed from the accelerator via ventilation.

The Electron Ring Accelerator (ERA) project was an experimental design for a quick, high energy accelerator. There were some experimental tests and theoretical analysis to demonstrate only slow acceleration. The program was not successful, because they showed that only slow (not "quick") acceleration was possible. The peak energy was approximately 5 MeV. The maximum current was thousands of amps. The unit accelerated electrons with a pulse duration of nanoseconds and a pulse frequency of 1 Hertz. The running time was about 2–3 years (20%–25% of the time). There were no radionuclides produced [in this project].

The laboratory was heavily involved in Research and Development work. Radionuclides used in research included pretty much everything in the periodic table in some amount. There were a number of projects that occurred, such as the production of medical isotopes, gram quantity production of uranium, and tritium labeling of compounds. Thorium was used sporadically, but primarily came along with other radioactive materials. Pu-238 and Pu-239 were handled at the HILAC to produce heavy elements, and by the Nuclear Physics group in Buildings 70 and 70A. There were µCi to mCi amounts of tritium, C-14, P-32, and other beta emitters used in medical research at LBNL and areas of campus. Originally, there was some plutonium in Buildings 4 and 5. There was some U-233 stored in the pit room. LBNL used a lot of chemical forms of radionuclides (e.g., oxides) and may have had high-fired oxides. Metal tritide targets were used at the 88" Cyclotron in the form of titanium tritide. They produced all types of accelerator targets and sources for LBNL and other facilities. Sealed sources were encapsulated. There is a small project with a radon generator.

LBNL made many of the heavy elements. Some of these elements were used as target material at the LBNL accelerators. The researchers started with plutonium, americium, and curium as the main material in the capsule. At different times, capsules were irradiated for one or more years at the Idaho reactors. The [irradiated] capsules were transported down to Building 70 and put into the hot cells for the separation of the produced heavy elements. The hot cell operators worked outside the neutron/gamma shield that contained a ventilated enclosure where the separation chemistry was conducted. The first step in the chemistry was to dissolve the capsule. There was a dead-end system (evacuated gas bottles with activated carbon) used only during the capsule dissolution process. The next chemistry steps were centrifuging and column chemistry to separate the heavy elements. These steps were performed in the same hot cell enclosure. The separated products were given to the LBNL researchers for analysis.

LBNL started out with a focus on cyclotrons for nuclear physics, but broadened into medical uses. The production of medical isotopes at LBNL started probably in the 1930s. The National

Academy of Science (NAS) did a study on production of medical isotopes, such as Tc-99m. The laboratory was involved in production and use of Positron Emission Tomography (PET) isotopes with short half-lives (e.g., F-18). The lab treated patients with neutron beams. There were some irradiations of patients with the cyclotron. They used radioactive isotopes to study biological and chemical interactions. LBNL Medical maintained a Human Use Committee that reviewed and approved the applications of radioisotopes with humans.

There were LBNL radioactive laboratories on the University of California - Berkeley campus conducting research. The Old Radiation Lab building was decommissioned and demolished in the mid-1950s. [Radioactive work was also performed at] Donner Laboratory, Calvin Laboratory, and a few other individual labs in large campus buildings. The Donner Laboratory was located on campus in Building 1. Donner Laboratory housed a clinic where they treated polycythemia with P-32 and thyroid cancer with I-131. There was a whole-body counter at this facility. There was possibly some actinide chemistry and some americium contamination. The Calvin Laboratory was located on campus in Building 3. They worked with C-14. Tritium work was initially done in Building 3 (Calvin Laboratory). They made tritiated compounds for biochemical researchers. There was concern that this work was being done too close to a population center, so it was transferred to Building 75 on the hill. The work conducted here was primarily for Biomedical and Radiopharmaceutical companies.

In Building 4 in the 1950s, researchers were trying to characterize the heavy elements (i.e., Am, Pu, Cm, etc.). There was a column separation to isolate the radionuclides. They were investigating the physical characteristics of the elements.

There was a tunnel underneath Building 46. There were very large sealed black drums as far back as the interviewee could see. The interviewee did not see any markings on the drums; some of the lids were rusty. The interviewee asked a laborer why these drums were there. The laborer said he did not know, but they had been there as long as he could remember. The parking lot for the building was above the tunnel. Building 46 was not ventilated and did not have air conditioning.

The National Tritium Labeling Facility (NTLF) was a source-making laboratory, which housed an analytical area, a pit room, an instrument repair and calibration shop, the dosimetry office, and other offices (not all at the same time, but over the years). Building 75 [NTLF] had a tritium tagging system. NTLF received various chemical compounds from inside and outside customers, and labeled these chemical compounds with tritium. Most of the tritium at the NTLF was organic material. They worked with curie-level tritium concentrations. The maximum tritium inventory at NTLF was 15,000–16,000 curies of tritium, which was stored in uranium beds. The uranium bed was heated to release the tritium into a vacuum tagging system. The tritium production area and the pit area had a separate ventilation system from other parts of the building. The tritium gas had to be converted to tritiated water to collect it on silica gel and dispose of it. The tritium diffused into the steel, which rusted. This was the only lab at LBNL that low-level radioactive contamination could be temporarily allowed. Organically Bound Tritium was handled at Donner Laboratory.

A study was done by the DOE, who came through and tested the laboratory for radon levels. LBNL has had no compromised Ra-226 sources.

The focus on high-energy physics has ended as time has progressed. LBNL expanded into materials work with radioactive material, molecular biology, and photon research at the ALS, which is the main focus now. The lab continues to look at alternative energy sources and is moving away from nuclear work. There have also been efforts in computer science.

MAINTENANCE

The interviewees with maintenance experience, collectively, provided their characterization of their radiation related work in various onsite facilities, as follows.

Many maintenance workers were assigned to specific areas, such as Buildings 51 and 71. Maintenance was available for specialty areas 24 hours per day, 7 days a week. There was also a regular dayshift crew. About 15 years ago, there was a consolidation effort, and maintenance migrated back to the Building 76 Central Shop.

Different trades helped each other if they needed to get the job done. For example, plumbers were responsible for underground repair work and installation of piping, and above and below ground plumbing. Pipefitters were responsible for installing new piping systems (i.e., there was a fine line between Pipefitters and Plumbers). Carpenters were responsible for any work done with wood or metal. They would tear down and put up structures. Carpenters worked closely with Riggers. A Plant Maintenance technician was responsible for the building utilities—ventilation, water, vacuum pumps, cryogenics, generators, heat exchangers, generators, air compressors and handlers, oxygen supply, and acid waste in some buildings (2, 70A, 76).

Mondays were routine maintenance days. On an annual basis, the Bevatron was shut down for a couple of weeks [for maintenance]. At the 88" Cyclotron, the unit was shut down in the summertime. At the Bevatron, they did cancer research. When there was a patient on the table, maintenance workers did whatever they had to do to get the machine going.

Maintenance workers entered unoccupied areas. They went in and around the ducting, ventilation system, all around the magnets, inside the shielding blocks, etc. A plumbing supervisor accessed every storm drain and sewage line onsite. There were numerous sewer problems with solvents and oils. One interviewee has been in the pit room, a pit area down beneath the Motor Generator (MG) room in Building 51. This was where the oil tanks for MG sets, resister banks, and sump pumps were located. In Building 71, there was something called the weeder row (a small tank with coils inside for particle acceleration). This area had lead shielding around it.

RADIOLOGICAL CONTROLS

The interviewees, collectively, provided their characterization of radiological control activities at LBNL, as follows.

Historically, the Radiological Control (RadCon) organization was divided into Health Chemistry and Health Physics. The Health Chemistry group was responsible for unsealed sources and contamination monitoring; they worked with the researchers that handled radioactive material in the field. They were responsible for minimizing external and internal exposures from radioactive materials by providing engineering controls, supporting operations, and surveillance services (e.g., air sampling, surface contamination monitoring, training, maintenance of protective equipment, etc.). The Health Physics group was responsible for the radiation-producing sources and machines, and for external dosimetry. They covered all of the penetrating radiation from machines, such as accelerators, x-ray devices, and neutron-generating machines. They also provided film badge services to the laboratory. The Medical Services Department operated the bioassay laboratory and whole-body counter for evaluation of internal exposures.

In the 1950s, Radiation Monitors (RMs) in the Health Chemistry group performed all radiation protection-related tasks, working with the researchers, nuclear chemists, doctors, etc., who handled radioactive material. The RMs worked side by side with the researchers and were hands-on. They were always there when there was a pass out from a glovebox or for other operations that required extensive monitoring. The RM delivered all the radioisotopes to the researcher and characterized/packaged the radioactive waste. An HP Coordinator evaluated research projects for radiological hazards, wrote permits and procedures, identified bioassay requirements, and established engineering controls. The RM contacted the researchers, found out what plans they had, and communicated the information to the coordinator. The coordinator would come see what was happening in the field. Health Chemistry workers were also involved with waste disposal, ventilation for airborne material, and shielding design for the radioactive laboratory, hood, gloveboxes and hot cells (caves).

The level of staffing depended on the director who was in charge and if they thought the scientists could do their own radiation protection. There were about 25 Radiation Monitors working throughout LBNL during the late 1950s and early 1960s. Coverage was provided 24 hours per day, 7 days per week, when Building 70 first started. The monitors kept up with the level of research. Currently, there are 30 individuals in radiation protection. Environmental Health and Safety (EH&S) has 160 people supporting about 4,000 laboratory employees.

Individuals understood the hazards of radiation and took care. People operated within the requirements of safety as defined by the safety staff. One interviewee noted that the largest interest at the laboratory was energy and research, rather than safety. The laboratory was not negligent about safety, but it was not as concerned with it. Historically, only 0.4% of the budget was devoted to safety. Larger amounts of materials were handled, and monitoring was not as strict. At some facilities, safety staff did not report to Health Physics/Health Chemistry. For example, at the Junior Cave (i.e., lead-lined gloveboxes), they used to hand-walk radioactive sources from the beams to the chemical separation area with tongs. There was a change at LBNL in the mid-1990s, motivated by the Tiger Team visit and later by the implementation of 10 CFR 835. The full transition of the radiation protection culture took about 10 years.

LBNL's philosophy was to confine and control radioactive material, instead of dilute and disperse. Low-level airborne radioactive contamination was not allowed in work areas. Air sampling includes high volume air samples, lapel air sampling, and general air sampling. There is routine air monitoring, including lapel air sampling and DAC-hour tracking, at the Heavy

Elements Research Laboratory, Building 70A. [In the heavy element separation facility], there was air sampling in the room in the hot cell (cave) and on the stacks. Tritium monitoring was done at the NTLF with Femtotechs, which are ionization chambers. No particle size studies have been conducted. General air samples were also collected, tracked, and archived from all over the laboratory. Every room where there was a possibility of airborne contamination had air samplers. General area air sampling units were placed as closely to the breathing zone as possible. The samplers were placed in the air flow pattern of the room; sometimes there were multiple units in a room. An RM was assigned to a room or station [office]. The RM's daily work included preparing technical smears and preparing the required information on the fixed and breathing zone filter paper air samplers. The RM would then exchange the air samples and take smears. If the air sample was elevated, the workers were required to submit a bioassay.

Health Physics was aware of the radiological hazards at the lab. LBNL is fairly clean as a site. Frisking surveys were done to check the areas where the scientists were working. Any spills or contamination spreads were cleaned up right away. There has been some legacy contamination encountered during D&D [decontamination and decommissioning]. For legacy contamination, there is some isotopic characterization for Buildings 51 and 71. There have been reconnaissance-level characterizations to identify activation products in structures. Very small activity of fine Am-241 powder was discovered in ducting at Building 4 on one occasion. Due to the complexity and cost of ductwork removal (issues with transite, asbestos, radiological contamination, and difficulty sealing the area from the floor below), it was left in place until the building demolition.

In the past, there was potential skyshine from Buildings 51, 71, and 88. This was particularly true when the accelerators had no shielding on the roof.

Engineering Controls have improved by leaps and bounds. For example, major improvements have been made in interlock systems. The lab has employed key control and relay logic. The LBNL accelerators (the 184", the 60" on campus, the HILAC and the 88") had systems designated to remove radioactive targets and be transported to chemistry and counting labs for analysis. All radioactive internal transfers were made by EH&S Transportation group.

At the ALS, they allowed immediate entry after beam shutdown. At the 88" Cyclotron, there was a delay period before entry. The length of the delay period depended on the types of targets used. There was no delay period after shutdown during patient treatments at the Bevatron, because the unit required immediate response. After an accelerator was shut down, a Radiological Control Technician would go and make radiation measurements. If there was a breech of the system of the 88" Cyclotron, Health Physics would do air sampling. Shielding was in place at accelerators.

One of the more difficult isotopes to work with is Cf-252, having alpha, gamma, and neutron emissions. Special shielding for neutrons and gamma were designed into hot cells (caves) to handle the produced heavy elements, including Cf-252.

Since 1948 to 1952, they started to develop gloveboxes. The original gloveboxes were wooden. EH&S had to do all the work in the case of design. They had a shop to build a glovebox. They had liners inside the glovebox, so they could be removed and replaced, so it could be used again.

They had to wipe the window. There were gloveboxes in Building 88. Maintenance workers repaired the gloves and cracked glass in this area.

LBNL had some kind of [work] permits [from the 1960s]. The coordinator would fill out a form describing the job and the recommendations on what to do. In the 1980s, the program became more formal, and the laboratory implemented work permits.

At various times, maintenance workers went to areas that were posted as contamination areas. Generally, Personal Protective Equipment (PPE) was not worn 25 years ago. In some cases, workers wore rubber gloves when working with chemicals, such as TCE and Freon R11. There was an improvement in this philosophy in the 1980s. PPE use was formalized in the 1990s after the Tiger Team came to LBNL. The Lead Standard and other standards came into being also. Plumbers wore Tyvec suits with an RM observing and monitoring the job. LBNL became more cautious as time went on, and new postings went up all of the sudden. Workers could no longer access all the areas they used to go to.

Every once in a while, administrative staff had to drop off documents at Building 75. On either side of the stairs and the walkway that led to the door, there were gas cylinders on both sides of the walkway. These cylinders were of every shape, size, and color. An interviewee had no idea what was in these cylinders, but everyone inside the building was working behind protective glass. Most of the workers wore white suits and gloves. Some of these employees were wearing full headgear or special masks.

Hand and foot monitors were stationed at exits from radioactive work areas. Portable instruments were maintained at radioactive work areas (e.g., gloveboxes and chemistry bench tops). Workers were required to monitor themselves when leaving and during radioactivity operations. Workers monitored their hands when pulling their hands out of gloveboxes and hoods. The RM did glovebox glove changes and monitored the gloveboxes themselves.

Surveys of the diagnostic x-ray unit were conducted, as well as industrial and analytical units; the surveys were maintained in a file at his desk.

Originally, workers were allowed to eat, drink, and smoke in the immediate vicinity of radioactive material. For example, maintenance workers drank beverages at their machines. They could eat a sandwich while they were machining. There were also drinking fountains in the operating areas. Now workers cannot drink or eat in the shop. This has been in effect for a while now.

X-RAY MACHINES

The interviewees, collectively, provided their understanding of how x-ray machines were used and controlled at the laboratory, as follows.

LBNL had three types of x-ray machines—medical, industrial, and analytical. They are addressed separately in ANSI standards. There was a group of individuals who designed x-ray machines at the laboratory. The lab had two industrial units used for irradiation and/or non-destructive testing, which were totally enclosed in heavily shielded vaults. These were 250 kVp

Picker teletherapy units. [Analytical x-ray units included x-ray diffraction and x-ray fluorescence.] The x-ray diffraction (XRD) units were originally open beam, which was normal for the time. X-ray fluorescence (XRF) and cabinet units were fully enclosed.

From 1979 forward, all the x-ray machines on the hill were enclosed. LBNL was the first national lab to enclose **all** analytical x-ray machines. LLNL was second, and others finally followed more than a decade later. Other national labs still use open beam XRD units. Enclosures were installed, so that body parts could not be put inadvertently into a beam. X-ray Safety had been trying to put forth a full enclosure and area monitor agenda for years, and he used the [1977 x-ray exposure] accident to put forth this agenda. Even with [the accident], it took more than a decade to get his access control agenda through. Area alarming monitors were placed on the units and key card activation was required. It took more than a decade to get the lab to spring for card key activation.

Health Physics X-ray Safety was notified of any alarms. They rewired the units, such that they had a failsafe interlock change and an "x-ray on" light by the power switch. Machines were allowed to have only one button to start the machine. In 1985, they also adopted ANL's idea for placing a form of alarming area dosimeter on the case. The routine users could not override the interlocks on their own, but only those with override authority could override the interlocks. They could override the interlocks **only** with a special key, and later, only if their card key access allowed override. This limited beam access to only a small percentage of the user population and only the most senior and experienced users. They were called "system operators." There was an audible alarm if/when the interlocks were overridden. The authorized users were trained by x-ray safety personnel, and they, in turn, trained the routine users. This corrected a lot of the problems associated with the analytical x-ray units.

EXTERNAL MONITORING

The interviewees, collectively, provided their characterization of how external monitoring was performed historically at LBNL, as follows.

Prior to 1980, all personnel were assigned dosimeters (film badge or TLD). Many laboratory personnel were assigned dosimetry badges who most likely would not receive an exposure. After 1980, dosimetry was assigned to Radiation Workers based on need. Workers wore their whole-body dosimeter at their chest. The film over-responded to lower energy photons. Electron accelerators produce muons, but there is no special monitoring for this. Radiation Monitors received some of the highest doses at LBNL as they assisted with the work.

Early in the 1980s, the site switched to TLDs that were capable of detecting some neutrons. The CR-39 was implemented in the 1990s for the detection of high-energy neutrons (4–5 MeV). In the last 10 years, neutron energies were moderated with shielding.

There was an error in the neutron dose discovered in 1979 or 1980. The dosimetry technicians relied on a chart to translate the number of tracks into dose. For readings of 1 or 2 tracks, the chart was off by a factor of 10. For example:

1 track = 40 mrem (should have been 4 mrem)
2 track = 80 mrem (should have been 8 mrem)
3 track = 12 [mrem]
4 track = 16 [mrem]

This misinterpretation occurred from ~1970 to roughly 1980 and resulted in an overestimate of neutron doses. The badge readings with 1 or 2 tracks were misinterpreted, but readings of 3 or 4 tracks were correctly interpreted.

When the neutron dosimetry errors were discovered, they were not corrected and workers were not notified. This problem was discovered by an interviewee who notified dosimetry of the problem. Where these errors are should be very obvious and numerous in the record. Real exposures that high were very rare and only within a very small group of workers. These errors will appear as chronic exposures, and LBNL just did not have any such chronic exposures.

Typically, there were no non-uniform radiation fields. There were a handful of projects with extremity dosimetry, and electronic dosimeters were used in some situations. The researchers working in areas where an extreme exposure can occur (for example, working in junior caves, time limit entry) wore hand dosimetry. After palm films, there were finger rings. Target handlers at the 88” Cyclotron used multiple dosimeters.

The XRD users were not required to wear extremity dosimetry. The users could not do their work with them on. The beams were collimated. As a precaution, the area monitor would go off if the beam was not collimated. They didn’t think the extremity dosimeter would catch the beam. Enclosures, area monitors, and access controls were imposed and designed to prevent exposure as best they could. Prevention seemed more prudent than monitoring, as stated in a paper at the Denver X-ray Users Conference (about 1985).

Dosimetry investigations were done for unexpected results. The film would show suspicious results (i.e., running through airport x-rays, etc.). They would have to interview the person to determine the cause.

INTERNAL MONITORING

The interviewees, collectively, provided their characterization of how internal monitoring was performed historically at LBNL, as follows.

LBNL was responsible for their own bioassay analysis until recently [~2006]. The bioassay program was part of the medical program for a period of time. Health Physics was responsible for determining who was monitored. Health Protection also issued work restrictions at established levels for bioassays. The bioassay laboratory was separated out after about the mid-1990s. Presently, LBNL contracts with the Savannah River Site to analyze their samples.

There was a routine urine sampling periodically for those working with radionuclides. If an individual worked with radioactive material, they submitted bioassay samples once per year, or more frequently, in some cases. Nuclear Chemists were on an isotope-specific bioassay program. For example, at Building 51, bioassay was collected for a little bit of everything.

Weekly tritium bioassay samples were collected at NTLF. Tritium was measured in urine in terms of μCi/liter. There was no routine fecal sampling program. One interviewee recalled collection of a pre- and post-job sample during a job at Building 70A. Urine and fecal samples were collected after an incident. Some blood samples may have been taken at one time.

Many of the samples were 24-hour samples (collected over a 24-hour period), with some spot samples. Bioassay samples were collected at the lab and home. Early bioassay data are usually recorded as gross alpha or gross beta, with some exceptions. This reporting practice continued into the 1990s.

Internal dose monitoring is presently based on the requirements specified in the LBNL Internal Dosimetry Technical Basis Document. Bioassay requirements are communicated through Radiological Authorization documents by the project. These documents also prescribe PPE and other requirements. There is a pre-qualification bioassay collected before an individual works with materials. There are about 15–20 bioassays per year combined for americium, plutonium, uranium, curium, neptunium, tritium, I-123, I-125, and I-131. Iodine bioassay is done for those involved in the Medical Research program.

There was a whole-body counter in the basement of the Donner Laboratory (Building 1) used to count some workers. Thyroid monitoring was done at LBNL for individuals who worked with iodine. In the clinics, they had thyroid monitors. The results of this monitoring would be in the medical records. Now there is a contract in place with LLNL for whole-body counting services.

The NTLF had the largest potential for uptakes (i.e., tritium), and then the animal house area. There were no workers with consistent detectable body burdens.

There were no audits that identified deficiencies in the internal dosimetry program. Gaps in bioassay data would occur when certain individuals didn't turn in their urine sample on a timely basis.

INCIDENTS

The interviewees, collectively, provided their recollection and understanding of what incidents occurred at the laboratory and how they were handled, as follows.

In 1977, a severe radiation accident occurred involving an individual who inserted his hands into the beam of a cabinet x-ray machine without realizing that it was on. The old mechanical relays on the machine were noisy, and when one of them caught fire, it was replaced it with a solid state relay (SSR). The old mechanical relay interrupted both legs of the 220 v. When the SSR was put in, one leg was shorted through and the SSR only interrupted one leg. Furthermore, there was no snubber network placed across the triac on the SSR, as was recommended for triacs firing into inductive loads. The failure was highly predictable.

The warning light could not be wired across the primary of the high tension transformer, since the voltage was varied over a wide range, and the light would go from extremely dim to short burnout bright. So the light was wired across the control winding of the SSR. The beam stayed on, but the current was varying, so the light went on and off. However, there was a large and easily seen working mA meter in place at eye level, right above the cabinet door (next to the light), which was giving a very clear mid-scale reading that there was current going through the x-ray tube and, thus, that x-rays were being produced. In haste, the technique used by the individual to turn on the machine was to reach up and actuate the ON switch as he was walking and facing away from both the meter and the light. Evidently, he paid no attention to the meter as he opened the door. The ozone smell was strong [another indicator of x-ray production]. The accident resulted in permanent injury.

Other Incidents

A file was compiled of the various incidents. During the high production era, there were more spills. An RM was required to be there when there were high-risk tasks. When the researchers were handling radioactive samples, there was a potential for contamination. There were a few cases were contamination was tracked into non-controlled areas; these would be documented in incident reports in EH&S archives.

Occasionally, there was some skin contamination. Initially, the researchers were on the honor system to report to the RMs if something happened. The RM would survey the individual, perform the initial decontamination, and send the individual to Medical. In the later years, an RM monitored the process and individuals were referred to Medical for decontamination. Medical saw several individuals that were contaminated mostly at low contamination levels. There were some suspect wound contaminations, but no uptakes through absorption. There were no other acute radiation effects, except the x-ray exposure incident. Several individuals were chelated once with Ca-DTPA via aerosol chelation. They had activity in the nose and mouth, and were chelated because of a potential exposure to Am-241. The urine did not show an uptake as a result of the accident. LBNL had to report the use of chelation to Oak Ridge, who should have further information.

In 1959, there was an incident at HILAC involving Cm-244. Curium was sputtered onto a foil. The foil had to be kept cool. The pressure was turned on before the exhaust, and the plated particles became atomized and drifted out. There were particles floating around. There was a Cm-244 release inside Building 71, which was blown outside by the ventilation. The RM evacuated the buildings. The staff in the area received bioassay sampling as a result of the incident. Although there was not much of an uptake, there was a large decontamination effort for several days, because the particles dispersed throughout the building. The contamination was loose and could become airborne, requiring the decontamination workers to be suited up and wear respirators. Air sampling was done during and after the clean-up.

On one occasion, a researcher who had been working with americium and plutonium at LBNL transferred to another DOE site. His pre-employment body count at discovered americium, and as a result, LBNL had to do some research and determine if [an uptake/release] had occurred.

In the early days, when they were injured, a band-aid was put on the wound and they just returned to work.

The DOE activated the Radiation Assistance Team (RAT) from LBNL. Those involved worked with the local emergency response agencies. During the response to one incident, the workers were contaminated with thorium oxide.

[LBNL had situations where individuals were exposed on purpose.] Astronauts from NASA reported they had seen flashes in their eyes as a result of activation of the fluid in their eyes. To determine the cause, LBNL staff placed their heads in the beam of the 184" Cyclotron to see if they could reproduce the flash of light. There were personnel who injected themselves with radioactive material to evaluate biological effects (e.g., chromosomal abnormalities), or to determine the effectiveness of personnel monitoring techniques. There were also a few individuals who took radioactive material home.

MEDICAL

The interviewees, collectively, provided their characterization of how medical monitoring was performed historically at LBNL and how radiological records were maintained, as follows.

Medical was known as Medical Services and Health Services. Medical Services created an annual report, which was distributed to the superiors. This report included the number of exams completed, the number of bioassay samples collected, the number of laboratory samples collected, and participation in the Employee Assistance Program (EAP). EAP eventually went to the campus.

At first, there were no health services at LBNL; just a first aid station. They then introduced pre-employment exams, and finally regular physical exams with a chest x-ray. All the exam requirements were determined by the AEC and ERDA. Occupational medical requirements can be found in DOE Order 5440. Routine exam frequencies were based on age. One interviewee stated that the frequency of x-rays taken with the exams was annually, then biannually, then every 5 years, and finally discontinued for most people. Some individuals were required to have periodic x-rays because of the Be, Pb, asbestos, and silicosis standards. There was a pre-employment exam with x-rays (up to about 1990). At pre-employment exams, posterior-anterior and lateral chest x-rays were taken.

Initially, workers had to be taken offsite to get x-rays, because there wasn't an x-ray facility onsite at first aid. Offsite x-rays stopped by 1964, if not sooner. LBNL had a Picker x-ray unit that was put into Building 26 about the time it was built. Health Physics did surveys on the diagnostic x-ray units with a phantom using their techniques. The vendor did the maintenance—regular servicing—on the x-ray units.

X-ray retakes were less than 10%. LBNL never did lumbar spine x-rays. There were no photofluorography x-rays found in the medical files. Most of the films in the records are the standard size of x-rays (14" x 17"). The nursing staff was cross trained to serve as x-ray technicians. Part of the training of the x-ray technicians was done by an outside agent who supported LBNL.

[Medical had] a Co-60 teletherapy source for a while, which was used as a research tool for primarily animal studies. In the 1930s, they had the electroscopes. They did do some blood tests to check for decreases in white blood cell count.

RADIOLOGICAL RECORDS

The current dosimetry database, REM, contains data from 1981 or 1982 forward. There was a predecessor database. The bioassay data back to the 1960s was put into an Access database. The ORAU Team was provided with a copy of this database. Now there is so little data to store, it is maintained in hardcopy. A copy of the bioassay results would be put into the medical file, but a duplicate was maintained by the Radiation Protection department. This was because all medical data had to be included in the individual's patient file.

Historically, some workers reported receiving dose reports quarterly. They recall positive results. Health Physics switched the monitoring frequency to annual. Now workers typically get zero dose.

ENVIRONMENTAL MONITORING

The interviewees, collectively, provided their characterization of how environmental monitoring was performed historically at LBNL, as follows.

Environmental work fell under Health Physics and Health Chemistry Department. Health Chemistry was responsible for stack emissions. Health Physics was responsible for doing penetrating radiation monitoring. There was a separate group responsible for Radiation Emissions. These functions [eventually came under] the Environmental Protection Department.

The environmental monitoring program has consisted of collected stack air, ambient air, surface water, ground water, vegetation, soil and sediment, and even goat urine and milk samples. The goats are brought onsite during the summer months to clear grasses and weeds as part of the lab's wildland fire management program.

Historically, LBNL monitored all 120 stacks that had the potential for release of radionuclides. Currently, they monitor 12 stacks. The details are provided in the Annual Radionuclide Air Emission Reports. In 1995, there was a budget cut and thus a reduction in the environmental monitoring activities. The number of monitoring points had built up before this because of the Tiger Team Assessment. Currently, LBNL routinely analyzes the stack air samples for gross alpha and gross beta, H-3, C-14, and I-125. Positron emissions are monitored at the 88" Cyclotron stack and the Building 56 Cyclotron stack.

There were [air] releases from the 88" Cyclotron irradiation vault, the NTLF, and Building 64, where they produced medical radioisotopes (e.g., C-11, F-18, all Positron Emission Tomography isotopes). Tritium releases occurred while the NTLF was in operation between 10 to 30 years ago. The last major tritium release occurred about 10 years ago. Building 64 had very tall stacks with a poor stack monitoring system. The detectors were not stable instruments. Part of the problem with measuring the effluent from the stack is that the air passes the sampler too fast.

Up until the closure of NTLF, there was also tritium analysis of ambient air samples. The lab monitored tritium using critical orifices and sampling 10 cubic centimeters per minute. Tritiated water (HTO) and elemental tritium (HT) were considered in the environmental reports. The elemental tritium was analyzed by direct counting, or was converted to water vapor and analyzed by liquid scintillation. The program for monitoring tritium in ambient air fluctuated.

There was a study conducted on the retrospective releases of tritium from LBNL. Scientists analyzed the tritium content in eucalyptus tree cores, because there was a grove of eucalyptus trees around the tritium stack. This study may provide some information on early tritium work.

The ambient air sampling stations are three perimeter monitoring stations on the east end, west end, and near the Hazardous Waste Handling Facility. There were more stations in the past. The annual reports provide the location of the stations. Ambient air samples are analyzed for gross alpha and gross beta.

The external ambient monitoring has been done with TLDs or real-time gamma/neutron monitors. Initially, external environmental radiation levels were monitored at the perimeter using GM tubes (1 foot long by 1 inch diameter) for photon measurements. Levels were continuously integrated and were recorded and stored in 10-minute groups so nothing was missed. The GM tube was more rugged, constant, and environmentally more stable than ion chamber or scintillator instruments of comparable sensitivity. There is known to be a seasonal variation in background radiation. These GM units are sensitive enough to detect that variation consistently year after year. In fact, they were also sensitive and stable enough to detect a decrease in terrestrial radiation, due to shielding from soil saturation during rainfall. Personnel looked for this kind of sensitivity as it indicated that the units were sensitive and stable enough for use as environmental monitors. Previously used instrumentation could not detect these slight variations.

Environmental Monitoring deployed jugs of water and TLDs to measure environmental neutron dose. Neutron exposures are measured in rads or rem. There was also a photon badge on the jug as well. These were placed around the radiation sources, especially in line with concentrations of unmonitored personnel (employees and general public) and in public areas of greatest concentration of unmonitored personnel. The "in close" monitors would alert them as to when they might most probably find some indication on the monitors in populated areas, since they [the "in close" monitors] were statistically better indications. Then they could pay closer attention for the possibility of a smaller (statistically less significant) indication on the population monitors.

There was a study of the maximum depth of penetration. There was some neutron dose off the back of the 88" Cyclotron when it was running light ions. They had recording instruments to make continuously integrated measurements, with the integrals recorded in 10-minute groups. There were no problems with the other accelerators.

There are currently eight dosimetry stations and three gamma/neutron stations, although this has changed over the years. There was an equipment upgrade in the early 1990s. Penetrating radiation (gamma/neutron) monitoring locations are at the west end of the site, around ALS, and offsite (across the valley).

Never was anything attributable to lab operations detected at the "Panoramic station," the one across the valley. There were no detectable levels during routine operations of the ALS at the fence-line monitoring station. Under a very rare fault condition, a difference could be detected at the boundary when the ALS unit was on or off. A measurement of 6 microRem/hr was obtained off the ALS for this very rare fault condition when it was continuously in injection/fill mode for almost a week. This could only be detected when the ALS was stuck in injection over a long time. This is absolutely the worst case condition the ALS could be in. This measurement had a confidence level of 17 standard deviations. In a conversation some time later, it was suggested that this was probably one of the smallest neutron dose levels ever measured.

Ground water underwent analysis for gross alpha, gross beta, gross gamma, tritium, and Cm-244. They have analyzed for plutonium isotopes in sewer water. They perform gamma spectroscopy on soil and sediment samples. There is a ground-water tritium plume that extends south from the area of the former NTLF. Soil near the former NTLF is also contaminated with tritium. Low levels of Cm-244 are present in the soil near Building 71. In 1985, radioactive contamination was detected in the soil near Building 5. The contaminated material was removed.

All of the drinking water for the site is supplied by the East Bay Municipal Utility District, and not from onsite wells.

There was an incinerator at LBNL, but it was not used. No burning activities occurred.

Annual environmental reports for 1995 to the present are available at the web site. The lab has hardcopies of these annual reports going back even further. The annual environmental reports contain information on routine and incidental releases. The environmental monitoring stations are described in an old paper by the original designer, and two additional papers were written after instrumentation and telemetry upgrades. All three papers were presented at various HPS meetings.

[Environmental Services] has done some isotopic characterization for a few of the D&D projects, and plans to do more in the future. The Environmental Restoration Program has prepared a summary of radionuclide investigation reports for the investigations they have conducted.

The state of California is not involved in environmental regulatory issues, including monitoring, although there is some involvement in waste management activities. The EPA has some authority at the site under the radionuclide NESHAPs regulation. There was a 1988 DOE environmental survey summary report. There were no aerial gamma surveys done at LBNL.

In the Tiger Team review, the main environmental issues raised were lack of formality and documentation in the program. The assessments resulted in a better management commitment and more resources.

SITE PROFILE COMMENTS

RadCon staff indicated the material in the site profile is correct, and that NIOSH captured the dosimetry program well. Information related to x-ray equipment is also correct.

MISCELLANEOUS COMMENTS

- The laboratory learned from their experience on the 184" Cyclotron and applied this to building the calutrons in Oak Ridge. After WWII, they didn't use calutrons, because they were not as cheap as the gaseous diffusion process. Centrifuges, developed later, are also cheap.

- A Class Action lawsuit was filed against LBNL because of unauthorized testing of minority employees for pregnancy, syphilis, and sickle cell anemia. Even though the lawsuit was resolved in 1999, the workers were never told why these tests were performed, where their personal/private information was, and who has/had access to it. An article about the lawsuit states, "The newspaper's series prompted Energy Secretary Hazel O'Leary to open up government files that disclosed a pattern of federally sponsored radiation experiments on human subjects."

- There were two copy centers on site—Building 50 and Building 90. They were used to complete large copying projects. Administrative workers would change toner cartridges and clear jams that were inside these large copy machines, as well as cartridges from copy and fax machines in the daily work area. The workers often got toner on hands, arms, and clothing. If [the hazard had been communicated], these workers would have changed these cartridges with more caution.

- Administrative offices in Building 80 had broilers for heaters. The broiler pipes were wrapped with material containing asbestos. An interviewee was told that as long as no one touched the material, there would not be any problem. This material was not removed or altered in any way before, during, or after the group moved into this building. The administrative staff had no access to windows and no sound buffers from the [construction] work that was being done down below on the first floor. There were very loud noises and smells. At times, there were [disturbing] odors coming up from the bottom floor.

- The Advanced Light Source (ALS) began its initial phase in Building 46. Down from the administrative working area, there was a shop that at times did small welding jobs. Every so often there would be a burning smell coming from this area. The smell was putrid and it lingered. The building was not ventilated well and did not have air conditioning.

- There are a number of confounders for cancer. For example, sugar has been demonstrated as a confounder for Non-Hodgkins Lymphoma.

ATTACHMENT 3: ISSUE RESOLUTION MATRIX FOR SC&A FINDINGS ON THE LBNL SITE PROFILE REVIEW, ORAUT-TKBS-0049

Issue 1: Inadequate Documentation of Historical Operations and Sources of Radiological Exposures

SC&A Finding: This review found that the site profile provides an inadequate overview of LBNL historical operations and the primary radiological exposure sources and conditions. The document lacks sufficient detail and analysis to provide comprehensive guidance to dose reconstructors. The period covered is large, as it is for several of the other DOE sites; however, the TBD failed to fully address the exposure implications of radiation sources to the degree necessary to allow a comprehensive assignment of historical doses, including missed doses. Specific operations and facilities are not discussed in sufficient detail. Examples of the lack of significant detail and information are the lack of coverage of the National Tritium Labeling Facility (NTLF) and the accelerator program at LBNL.

NIOSH Response:

SC&A Reply:

Work Group Actions:

Board Action:

Issue 2: Insufficient Information for Internal Dose Reconstruction, Especially during the Early Years

SC&A Finding: There is insufficient information on bioassay monitoring before 1961, and the information on air sampling and building activities is not sufficient to calculate the workers' dose due to internal exposures. Workers were potentially exposed to a diversity of radionuclides at LBNL, and the TBD is incomplete in relation to the periods of time and quantities of radionuclides that were handled in the different areas.

Table 5-4 of the TBD lists minimum detectable activities (MDAs) for in-vitro measurements, but is incomplete with regard to the totality of radionuclides that were handled at LBNL and their MDAs. The information on MDAs on the various periods is incomplete, posing a problem with the calculation of missed doses.

Gross alpha, beta, and gamma analyses are reported as being used for the entire site operation, including the present time. The TBD does not discuss the fact that many radionuclides present at LBNL would not have been detected by gross measurements, or at least detected with low recoveries and resulting high minimum detectable concentrations (MDCs). In addition, the use of gross measurements results in an indeterminate MDC for a specific radionuclide.

NIOSH Response:

SC&A Reply:

Work Group Actions:

Board Action:

Issue 3: Special Forms of Tritium and Plutonium not Addressed by NIOSH

SC&A Finding: NIOSH fails to identify in the site profile that metal tritides and organically bound tritium (OBT) are included in the materials used at the site and that tritium was used extensively at LBNL, in particular at the NTLF, Building 75. There is very little discussion about tritium exposures in the internal dose section (Section 5.0) of the site profile.

During the interviews, health physicists stated that it was possible that highly oxidized/high-fired forms of actinides were handled at the site. They stated that the most likely source of exposure to these forms would have been related to the production of sealed sources and targets that were made for use at LBNL and other national laboratories. It is possible that NIOSH is addressing this issue for plutonium exposures at LBNL; however, the site profile does not address high-fired forms of other actinides (thorium, uranium, etc.).

NIOSH Response:

SC&A Reply:

Work Group Meeting:

Board Action:

Issue 4: Bioassay Data Completeness and Adequacy have not been Verified

SC&A Finding: During the site visit by SC&A, it was determined that the bioassay database does not contain all bioassay data for all workers; therefore, it appears that the database may be incomplete. In addition, bioassay submittals were delinquent by at least 1 year in some file records. This delay could increase the minimum detectable doses significantly, especially for soluble and short-effective half-life nuclides.

In Tables 5-1 through 5-5 of the TBD, NIOSH listed many in-vitro and in-vivo bioassay methods, along with information on frequency of sampling. Given the great number of radionuclides that could have resulted in internal exposures at LBNL, it is apparent that many of these are short-lived, relative to the bioassay frequency.

During the site interviews, it appeared that work conducted at the Donner Laboratory and other laboratories at the University of California – Berkeley campus was not monitored and/or controlled as stringently as at other LBNL facilities. NIOSH should investigate the possibility that internal dose information (bioassay and air sampling data) for the work at these laboratories is adequate to reconstruct doses at these locations.

NIOSH Response:

SC&A Reply:

Work Group Action:

Board Action:

Issue 5: Insufficient Justification for Selection of IREP Energy Range Fractions for Photon Exposures

SC&A Finding: In Table 6-2 of the TBD, beta and photon doses are assigned to energy ranges according to the radioactive materials used in individual buildings at LBNL. For Buildings 51 and 71, a single photon energy distribution is given, and 10% of the measured dose is assigned to the 30–250 keV range and 90% assigned to >250 keV. It appears that this photon energy distribution is being applied to the entire history of accelerator use at LBNL. It is questionable that this energy distribution is appropriate in all situations and timeframes. In the early years, it is much more likely that technicians and others would be exposed to low-energy emitters shortly after a machine was powered off, or even during operation. This was presumably less likely as energies and risks grew larger and commensurate standards and protective practices evolved.

Regardless of the precise fraction that should be assigned, the choice of less than 100% to the 30–250 keV category should only be made where there is supporting evidence. As it stands, the selection of a 10% fraction is not claimant favorable and not buttressed by the inclusion of supporting evidence. Although the other buildings have been assigned factors greater than 10% for the more claimant-favorable 30–250 keV photon energy range, the fact that the accelerator buildings have been assigned a single low factor creates doubt on the validity and process by which the other factors were determined for the remainder of the site.

NIOSH Response:

SC&A Reply:

Work Group Actions:

Board Action:

Issue 6: Insufficiency of Neutron Dosimetry Treatment

NTA Film Energy Threshold Determination: As has been the case in a number of site profiles prepared by NIOSH, there is an inconsistent approach to the energy cut-off for the NTA neutron dosimeter. Callout "c." in Table 6.5 references NIOSH 2002 as listing the NTA lower energy threshold at 500 keV. Yet attribution number 47 discusses 800 keV as the threshold, and this is used as the basis for this TBD. Other sources list 1,000 keV as the threshold for NTA response. The assumption that NTA film responds down to 500 keV is not justified by the technical data and is not claimant favorable.

Failure to Adjust Recorded Doses to Correct for Lack of Response of NTA and CR-39 in the Intermediate and Thermal Neutron Energy Range: Table 6.6 of the TBD, "Adjustments to Recorded Dose," defines the corrections for photon and neutron dosimeters to adjust the measured quantity. However, no adjustment is indicated for the failure of NTA film to respond to intermediate energy neutrons. As presented, a significant part of the spectrum is inappropriately monitored and uncorrected.

There is virtually no discussion of the potential for neutron fields throughout this historical facility. Given that LBNL was a world leader in accelerator development, and given the leading-edge high energies developed by the machines, it is likely that there was the potential for unanticipated radiation fields and possible neutron exposures across a range of energies, especially in the early decades.

There is a remarkable silence as to thermal or slow neutron exposure in the site profile document. A search of the "O" drive revealed only a single document that mentioned slow or thermal neutrons. Clearly, there was the potential for exposure to slow neutrons, as slow neutron electroscopes were in use in 1956 and readings were documented for several individuals.

It is unclear from the TBD how and when albedo TLD data were merged with CR-39 results. The gap in neutron response from above the cadmium cutoff to the lower energy threshold for CR-39 (also not mentioned, but assumed to be around 150 keV) is not discussed. NIOSH should evaluate the neutron program and determine how missed intermediate energy neutron dose should be determined for this period, as well as intermediate and thermal energy neutrons for the NTA and pre-NTA years.

Selection of Minimum Detectable Dose for CR-39 Dosimeters: Table 6-1 of the TBD shows that the MDL for CR-39 is 10 mrem, with no attribution provided. The Los Alamos TBD shows an MDL for CR-39 of 20 mrem. The current commercial service available from Landauer, Inc., also shows an MDL of 20 mrem. It is likely that the MDL for CR-39 is higher than 10, and more likely around 20 mrem. This number is important and it is likely to be amplified to take account of missed dose not only due to exposure below the detection limit (DL), but also to estimate dose due to lower energy neutrons that would have been missed entirely due to the inability of CR-39 to detect lower-energy neutrons.

Use of Neutron-Gamma Ratios for Situations Where Neutron Data are Lacking - Seeming Inconsistency Between the Environmental and External Dose Sections: Table 4.1 of the Environmental Occupational Dose section (Section 4.0) of the TBD contains estimates of annual environmental dose throughout the history of the facility. The values provided are totals of neutron and photon exposure.

The Environmental Dose section utilizes a ≥70% factor and the External Dose section utilizes a 42% factor. This significant difference in the average site-wide neutron-to-photon ratio is surprising. It is possible that the environmental dose includes more sky shine and other factors; however, this issue needs to be addressed and the large difference explained.

This section on the determination of missed and missing neutron exposure needs a thorough review. Both the source terms and the dosimeter response specifications need to be addressed.

NIOSH Response:

SC&A Reply:

Issue 6: Insufficiency of Neutron Dosimetry Treatment

Work Group Actions:

Board Action:

Issue 7: Failure to Justify the Shallow Dose: Deep Dose Assumption

SC&A Finding: The TBD provides guidance on the dose to be assigned in the "early" years (pre-1979) for which there is no record of beta exposure. In the general case, there is an assumption that a factor of three for the ratio of shallow to deep dose is reasonable and claimant favorable. However, LBNL had a broad mandate.

In most cases, the site description does not provide sufficient detail as to the quantities, forms, and methods under which these materials were handled. What is known is that the levels of protection in the 1940s, 1950s, and 1960s were far from what would be considered good practice today.

There is no mention of head and eye dose or non-uniform whole-body irradiation in the site profile. Typically, workers handling beta emitters and those performing maintenance inside accelerators can be exposed to significant non-uniform fields. Likewise, there is no mention in the TBD of potential skin and clothing contamination and resultant exposure.

It is unclear from the TBD if workers were exposed to significant shallow dose, with possibly little deep dose to be used as an indicator. Possible activities that may have been conducted include fume hood operations, maintenance of accelerators, ventilation and plumbing systems, waste disposal operations, and spill cleanup. The lists of nuclides are extensive and include beta emitters, including some pure beta and low-energy x-ray emitters. For some personnel, the 3:1 ratio may not be claimant favorable. NIOSH should identify the workers who could have received exposure from these beta or low-energy x-ray emitters, or provide an alternative method of estimating the shallow dose in a claimant-favorable manner.

NIOSH Response:

SC&A Reply:

Work Group Actions:

Board Action:

Issue 8: Uncertainty in Beta-Gamma Dosimeter Response to Radiation Types and Energies

The Use of Early Electroscope Data Needs Greater Definition: Page 39 of the TBD describes the use of electroscope data as follows:

> *… Exposure data were recorded by film badges and thermoluminescent dosimeters (TLDs). Early exposure records also provided electroscope (or at times, electrometer or E was used) results, which supplemented the results measured by film. Dose reconstructors should use the electroscope results in a qualitative manner because no data were found on the calibration or energy response of these devices; they should use the film or TLD results to estimate the actual exposure or the electroscope reading if no corresponding dosimeter reading exists.*

A search of the "O" drive found that, anecdotally at least, there were significant problems with electroscopes. A study performed November 23, 1953, by Jim Bennett (Bennett 1953) showed that readings from the three electroscopes tested were widely divergent from the film that was exposed with them. Two gave a 10% response compared with the film, and the third was off scale. No details are provided as to the energy of the gamma source used for the exposure. However, the memo provides a cautionary statement as to using electroscope data, even in a qualitative manner.

Dosimeter Response to Very High Energy Photons and Charged Particles: LBNL was a pioneer in the development of high energy physics (HEP) and in the search for exotic particles. The film and electroscopes in use in the early decades will likely not have been calibrated for energies above 1 or 2 MeV. NIOSH should evaluate the dosimetry and potential for exposure to radiation at energies above that commonly produced by radioisotopes. The detectors will have responded to some degree, but the correction factor size and sign are unknown and not mentioned in the TBD. The response of the detector element or film, for example, will depend greatly on the composition of the holder and filters.

NIOSH Response:

SC&A Reply:

Work Group Actions:

Board Action:

Issue 9: X-ray Exposures are Uncertain

SC&A Finding: Table 3-1 lists the entrance skin exposure (ESE) doses used for the posterior/anterior (PA) chest exam. It states that until 1975, all dose estimates are defaulted to those provided in ORAUT-OTIB-0006. There is no information identified as being available on x-ray equipment that was used prior to 1975. Depending on how one views this information, there is no indication that this default is claimant favorable for the years 1942 through 1975. NIOSH needs to better describe what measures were taken to determine what types of equipment were used. For example:

- Where did workers get exams between the years 1942–1975?
- Were medical records available and do they indicate if x-rays were taken?
- Were workers sent to alternate locations for exams and were those records researched?
- Did NIOSH research address the potential use of PFGs to screen workers up through 1960?

The TBD should be expanded in its discussion of the medical dose to address the issues indicated in the above questions in order to be considered complete.

NIOSH Response:

SC&A Reply:

Work Group Actions:

Board Action:

Issue 10: Uncertainty of Calculating Doses Prior to 1961

SC&A Finding: There is no information on how NIOSH is planning to reconstruct doses before 1961. In ORAUT-TKBS-0049:

- Table 5-1 lists the in-vitro types of bioassay, the periods, and the frequencies of monitoring. It does not contain any information that might be applicable to calculate doses for exposures before 1961.
- Table 5-4 lists the MDAs for various analysis results. The only pre-1961 information available is the MDA for gross alpha, and gross beta is for 1957–1961.
- Table 5.8 contains only one reference to exposures before 1961.
- Looking at the files for LBNL in the NIOSH OCAS Claims Tracking System (NOCTS), 24 claimants received compensation. Those were probably the most exposed workers, and 18 of the 24 claimants started working before 1961. There is only one bioassay record before 1961; a uranium urinalysis done in 1958.
- Looking at the 99 claimant files for LBNL who did not receive compensation, 31 started working before 1961. There is only one bioassay record before 1961; a C-14 breath analysis performed after an incident in 1959.

There is insufficient information related to bioassay monitoring before 1961 in the TBD.

NIOSH Response:

SC&A Reply:

Work Group Actions:

Board Action:

Issue 11: Inadequacy of Bioassay Analyses Presentation

SC&A Finding: There was a diversity of radionuclides at LBNL. The Occupational Internal Dose section of ORAUT-TKBS-0049 specifies that, "from 1960 to 1996, both in vitro and in vivo monitoring records and associated interpretations exist." In Table 5.4, MDAs are listed for gross alpha for isotopes of thorium, plutonium, curium, actinium, and neptunium. The same method and MDA are listed for Cf-252 from 1965–1995. There is a remark specifying that, "method descriptions note that uranium, radium, and polonium are not detected by this method (Author unknown, no date)."

Table 5.8, "Radionuclides and fraction activity by facility," is incomplete and difficult to use, in relation to discrimination between exposures during the various periods of time the rooms were used in the installation.

Tables 5.1, 5.2, and 5.4 describing in-vitro bioassay programs, methods, and MDAs are incomplete and do not give enough information on internal dose calculations for LBNL employees. Table 5.8 is also incomplete and difficult to use, in relation to discrimination between exposures during the various periods of time and the rooms used in the installation.

NIOSH Response:

SC&A Reply:

Work Group Actions:

Board Action:

Issue 12: Failure to Provide Sufficient Guidance for Unmonitored Workers

SC&A Finding: The TBD fails to provide guidance on how to calculate doses to workers without a complete description of the monitoring programs (Table 5.1), and on how to assign monitoring results to specific radionuclides and compounds. The TBD admits that, for many of the radionuclides, there is no specific information on the compounds with which they may have been associated.

Insufficient guidance is provided on estimating internal doses for unmonitored workers. The information on bioassay programs is incomplete, as well as the list of radionuclides and compounds handled at the facility during the different time periods and in different locations. The TBD suggests that unmonitored workers should be assessed using coworker data and the tolerance levels, if there is evidence that they worked with uncontained radioactive materials; otherwise, environmental data should be used. This suggestion cannot be followed using the information available in the TBD.

NIOSH should revise the site profile document to provide information sufficient for proper dose reconstruction, particularly for unmonitored workers.

NIOSH Response:

SC&A Reply:

Work Group Actions:

Board Action:

Issue 13: Inadequate Coverage of Occupational Environmental Dose

SC&A Finding: Section 4.0 of ORAUT-TKBS-0049, Occupational Environmental Dose, is incomplete and should be revised to provide a more comprehensive description of the historical environmental dose to workers at LBNL. The deficiencies and omissions are such that inadequate guidance is provided for dose reconstructors.

NIOSH assumes that the gamma and neutron environmental exposure is primarily from accelerators and, thus, using the maximum measured value from the onsite and fence-line monitors for a given year would be claimant favorable. NIOSH fails to discuss the possible exposure of unmonitored workers from irradiators. In particular, the Co-60 irradiator housed in Building 74 may have been capable of higher doses at locations at distances less than those to the site perimeter or onsite monitoring locations (LBNL 1995a).

Table 4-2, "Maximum site-wide annual median intakes (Bq/yr) via inhalation," contains the NIOSH best estimates of annual intakes. Except for tritium and C-14, the values in the table are based on gross alpha and beta measured values from the site environmental program.

While this may be a conservative assumption relative to the effective dose equivalent (EDE), this may not be claimant favorable for specific organ doses. For example, for exposure to I-131, where the committed dose equivalent per unit intake for the thyroid is almost two orders of magnitude greater than for Sr-90, the dose to the thyroid would be grossly underestimated. Given the wide range of radioisotopes used at LBNL, NIOSH should present a more claimant-favorable approach to dose reconstruction for radionuclides whose intakes were determined from gross alpha and beta measurements.

NIOSH Response:

SC&A Reply:

Work Group Actions:

Board Action: