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August 27, 2007

Mr. David Staudt
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Re: Contract No. 200-2004-03805, Task Order 1: Transmittal of Draft SCA-TR-TASK1-0018, Revision 1: Privacy Act-cleared version of *Lawrence Livermore National Laboratory Site Profile Review*

Dear Mr. Staudt:

SC&A, Inc., is please to submit Revision 1 of a draft report titled, *Lawrence Livermore National Laboratory Site Profile Review,* SCA-TR-TASK1-0018. Revision 0 of this report was forwarded to you on July 23, 2007, pending review for Privacy Act (PA) information. The document has now been revised in accordance with that review and has been cleared for distribution. Please note, however, that this report is pre-decisional and has not been reviewed by the Advisory Board for factual accuracy or applicability within the requirements of 42 CFR 82.

Should you have any questions, please contact me at 732-530-0104.

Sincerely,

John Mauro, PhD, CHP
Project Manager

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ADVISORY BOARD ON

RADIATION AND WORKER HEALTH

National Institute for Occupational Safety and Health

Lawrence Livermore National Laboratory Site Profile Review

Contract No. 200-2004-03805
Task Order No. 1
SCA-TR-TASK1-0018, Revision 1

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August 2007

Disclaimer

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S. Cohen & Associates: ***Technical Support for the Advisory Board on Radiation & Worker Health Review of NIOSH Dose Reconstruction Program***	Document No. SCA-TR-TASK1-0018 Effective Date: Draft — August 27, 2007 Revision No. 1 – PA-Cleared Draft
LAWRENCE LIVERMORE NATIONAL LABORATORY SITE PROFILE REVIEW	Page 1 of 168
Task Manager: __________________________ Date: ____________ Joseph Fitzgerald	Supersedes: 0
Project Manager: __________________________ Date: ____________ John Mauro	

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ACRONYMS AND ABBREVIATIONS

Advisory Board	Advisory Board on Radiation and Worker Health
AEC	Atomic Energy Commission
AERIN	LLNL Dosimetry Model for Heavy Metals
ALARA	As Low as Reasonably Achievable
Anti-Cs	Anti-Contamination Clothing
AP	Anterior-Posterior
AVLIS	Atomic Vapor Laser Separation
CAMs	Continuous Air Monitors
CDC	Centers for Disease Control
CFR	*Code of Federal Regulations*
Ci	Curies
CP	Control Point
CP1	Central Control Point
CR-39	Canadian Resin Number 39, a polycarbonate material used for neutron dosimetry
D-38	Depleted Uranium
DAC	Derived Air Concentration
DCF	Dose Conversion Factor
D&D	Decontamination and Decommissioning
DOE	Department of Energy
DNA	Defense Nuclear Agency
DOD	U.S. Department of Defense
DR	Dose Reconstruction or Dose Reconstructor
DU	Depleted Uranium
dpm	Disintegrations per Minute
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
EDE	Effective Dose Equivalent
EG&G	Edgerton, Germeshausen and Grier
EPA	U.S. Environmental Protection Agency
ESE	Entrance Skin Exposure
DTPA	Diethylenetriamine Pentaacetate

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FDA	Food and Drug Administration
GM	Geometric Mean
GSD	Geometric Standard Deviation
GZ	Ground Zero
H&S	Health and Safety
HEPA	High Efficiency Particulate Air Filters
HP	Health Physics
HT	Tritium Gas
HTO	Tritiated Water
HVL	Half Value Layer
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IMBA	Integrated Modules for Bioassay Analysis
INEEL	Idaho National Engineering and Environmental Laboratory
ISMS	Integrated Safety Management
IREP	Interactive RadioEpidemiological Program
keV	Kilo electron Volt
kVp	Kilovolts-Peak
kg	Kilogram
LANL	Los Alamos National Laboratory
LAT	Lateral
LBNL	Lawrence Berkeley National Laboratory
LiDT	Lithium Deuterium Tritide
LiT	Lithium Tritide
LINAC	Linear Accelerator
LLNL	Lawrence Livermore National Laboratory
LPTR	Livermore Pool-Type Reactor
LRL	Lawrence Radiation Laboratory
mA	Milliampere
MAA	Material Accountability Area
MAPPER	LLNL Dosimetry Database
MCW	Mallinckrodt Chemical Works

MDA	Minimum Detectable Activity
MDC	Minimum Detectable Concentration
MDL	Minimum Detectable Dose
MeV	Million-Electron Volt
MFP	Mixed Fission Products
mR	Milliroentgen
MT	Metal Tritides
MVA	Material Vault Area
MW	Megawatt
NCRP	National Council on Radiation Protection and Measurements
NIOSH	National Institute for Occupational Safety and Health
n/p	Neutron-to-Photon Ratio
NPL	National Priority List
NTA	Eastman Kodak Nuclear Track Film Type A
NTED	Nuclear Test Engineering Division
NTEE	Nuclear Test Electronics Engineering
NTS	Nevada Test Site
NVOO	Nevada Operations Office
OBT	Organically Bound Tritium
OCAS	Office of Compensation Analysis and Support
OSPs	Operational Safety Procedures
ORAUT	Oak Ridge Associated Universities Team
OTIB	ORAU Technical Information Bulletin
PA	Posterior-Anterior
pCi	Picocuries
PFG	Photofluorography
POC	Probability of Causation
PPE	Personal Protective Equipment
PPG	Pacific Proving Grounds
PROC	Procedure
PSO	Protective Service Officer
R&D	Research and Development

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REECo	Reynolds Engineering and Electrical Company
RFP	Rocky Flats Plant
RTNS	Rotating Target Neutron Source
SAT	Space Action Team
SC&A	S. Cohen and Associates
SEC	Special Exposure Cohort
SID	Source-to-Image-Distance
SFCP	Spent Fuel Climax Project
SNL	Sandia National Laboratory
SNLL	Sandia National Laboratory – Livermore
SNM	Special Nuclear Material
SOP	Standard Operating Procedure
SRS	Savannah River Site
SSD	Source-to-Skin-Distance
STCs	Special Tritium Compounds
TBD	Technical Basis Document
TIB	NIOSH Technical Information Bulletin
TLD	Thermoluminescent Dosimeter
TPSS	Two-Person Security System
USC	United States Code
WB	Whole Body
WBC	Whole-Body Count
Y-12 Plant	Y-12 National Security Complex

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1.0 EXECUTIVE SUMMARY

This report provides the results of an independent audit conducted by S. Cohen and Associates (SC&A, Inc.) of the technical basis documents (TBDs) that make up the site profile for the Lawrence Livermore National Laboratory (LLNL) developed by the National Institute for Occupational Safety and Health (NIOSH). This audit was conducted during the period of October 5, 2006–June 30, 2007, in support of the Advisory Board on Radiation and Worker Health (Advisory Board) in the latter's statutory responsibility under the Energy Employees Occupational Illness Compensation Program Act of 2000 (EEOICPA) to conduct such reviews and advise the Secretary of Health and Human Services on the "completeness and adequacy" of the EEOICPA program.

The LLNL was established in 1952 to meet the scientific challenges behind advancing nuclear weapons design and development. It was sited at a former naval air station outside of Livermore, California, and has been managed ever since by the University of California (albeit, that responsibility will be shared with other contractors pursuant to a recently announced operating contract award). The original nuclear weapons development mission has expanded over the years to encompass a diverse set of scientific engineering research activities. These include the following (DOE 1992):

- *Research, development, and testing of the nuclear weapons life cycle and related tasks*
- *Strategic defense research emphasizing kinetic- and directed-energy weapons*
- *Arms control and treaty verification technology*
- *Inertial confinement fusion for weapons physics research and for civilian energy applications*
- *Atomic vapor laser isotope separation for defense and commercial applications*
- *Magnetic fusion, including leadership of the U.S. effort on the International Thermonuclear Experimental Reactor*
- *Other energy research in basic energy sciences, atmospheric sciences, fossil energy, and commercial nuclear waste*
- *Biological, ecological, atmospheric, and geophysical sciences relevant to weapons, energy, health, and environmental issues, including assessment and guidance in the event of accidents and other emergencies*
- *Charged-particle beam and free-electron laser research for defense and energy applications*
- *Advanced laser and optical technology for military and civilian applications*
- *Support of the U.S. intelligence community, the U.S. Department of Defense, the U.S. Nuclear Regulatory Commission, and other Federal agencies*
- *Participation in the nationally directed initiative to understand the human genome at the molecular level* (Maisler 2005b, pp. 7–8)

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Site 300 at the LLNL is a 7,000-acre area established nearby in Tracy in 1955 to provide information essential to the physical and chemical characteristics of high explosives. These tests are commonly referred to as hydrodynamics tests. The radionuclides involved in hydrodynamics testing included depleted uranium (DU), thorium, tritium, and, at times, other radionuclides (e.g., Po-210, enriched uranium). Initially, hundreds of experiments were required for the development of a weapon; however, this decreased over time as scientists developed processes for this testing (Wagner and Diaconoff 1974). The Explosives Process Area was used to press, mill, machine, and assemble parts for testing. In addition, parts were evaluated for environmental effects by twisting, stretching, compressing, shaking, bumping, heating, chilling, corroding, and irradiating the parts and materials. The area housed a flash x-ray accelerator facility, several fixed and portable x-ray units, radiographic sources, and a Linear Accelerator (LINAC) to radiograph components (Batzel 1976a, Wagner and Diaconoff 1974, LLL no date).

The Laboratory has also been actively involved in supporting nuclear testing activities at the Nevada Test Site (NTS), the Pacific Proving Grounds (PPG), and other test locations where LLNL sponsored atmospheric, underwater, and underground nuclear weapons testing of their weapons designs, supported other laboratories conducting tests, conducted safety shots, and performed subcritical experiments. These tests started in 1953 and continued until the end of weapons testing in 1992, involving a large number of LLNL staff members who were present at these test areas before, during, and following nuclear detonations.

SC&A's review focused on the six TBDs that make up the LLNL site profile and applicable technical information bulletins (TIBs). These address Introduction, Site Description, Internal Dose, External Dose, Occupational Medical Dose, and Occupational Environmental Dose, as they pertain to historic occupational radiation exposure of LLNL workers. These TBDs were originally issued in 2005, but five of the six are currently under revision. The Occupational External Dose TBD (Thomas and Szalinski 2007) was updated in April 2007. As "living" documents, TBDs are constantly being revised as new information, experience, or issues arise. For the LLNL Site Profile in particular, interviews with NIOSH and the Oak Ridge Associated Universities Team (ORAUT) underscored their ongoing and extensive efforts to upgrade the existing TBDs.

SC&A's process included a review of the TBDs; a site visit to conduct limited site expert interviews, and identification and retrieval of documents (unclassified and classified); follow-up telephone and e-mail correspondence with site experts; and an exchange of questions and answers between SC&A and NIOSH. The TBDs were evaluated for their completeness, technical accuracy, adequacy of data, compliance with stated objectives, and consistency with other site profiles, as stipulated in the *SC&A Standard Operating Procedure for Performing Site Profile Reviews* (SC&A 2004). A complete list of the LLNL TBDs and other supporting documents that were reviewed by SC&A is provided in Attachment 1.

SC&A found that the site profile does not address occupational radiation sources beyond the more established and well documented ones, which is problematic given the tremendous diversity and radiological significance of many of these "other" radionuclides, as well as the steadily evolving nature of radiological controls, dosimetry practices, and recordkeeping at the site from the late 1950s through the 1960s and into the 1970s that may have contributed to information gaps critical to dose estimation. The two major oversights identified were (1) lack of dose estimation characterization and guidance for LLNL personnel involved in weapons testing, and (2) inadequate information relating to potential radiological sources and exposure at Site 300. The site profile TBDs provide no explanation for how dose reconstructions will be handled in cases where dose reconstruction cannot be done, as previously identified by NIOSH in other technical documents. Technical Information Bulletins (TIBs) and procedures (PROCs) have recently been developed, to provide additional dose reconstruction guidelines, particularly OTIB-0065 (ORAUT 2007e), which provides dosimetry coworker data dose reconstruction guidelines for unmonitored or inadequately monitored LLNL workers exposed to uranium. Future revisions to the LLNL TBDs should refer the dose reconstructors to these guidelines and discuss their site-specific application.

Internal monitoring information (bioassay, air monitoring, and radiological contamination characterization data) available for dose reconstruction, especially for those involved in testing and special projects, is limited, inadequate, or, in some cases, not available. While NIOSH has developed general guidance that may help address these problems for some of the internal dose reconstruction [e.g., OTIB-0002 (ORAUT 2007d), OTIB-0014 (ORAUT 2004a), OTIB-0018 (ORAUT 2005e), and OTIB-0033 (ORAUT 2005c)], no discussion is included in the TBDs regarding how these could be applied to LLNL. Again, this should be considered for inclusion in a future version.

There are major issues with verifying the accuracy and usefulness of the data in the bioassay electronic database (MAPPER). Bioassay data is not available prior to 1956 for gross alpha and 1957 for gross beta. There is limited bioassay data in the database for tritium, I-131, thorium, and other radionuclides handled at LLNL. The LLNL staff has indicated that some bioassays cannot be confidently associated with a specific person. The ambiguities in some analytes reported were that large negative results are included for later periods, and letters in the sample type column do not always indicate whether the sample was urine or fecal. Sample volume and mass must also be interpreted carefully. There are many inconsistencies noted in the way the MAPPER data are used to determine an individual worker’s dose. The use of this data for the internal dose coworker model is suspect and needs to be evaluated. The existence of bioassay results with what SC&A found to be classified datasets likewise leads to questions regarding the adequacy of information currently being provided in the claimant files.

The Site Description (Maisler 2005b) and Internal Dosimetry TBDs (Berger and Szalinski 2005) do not give adequate guidance on assessment of all potentially important radionuclides encompassed by the recognized radiological source terms. The TBDs identify a large number of historically used radionuclides by building; however, they do not provide guidance on how to interpret bioassay data with results in gross alpha and gross beta activities that clearly encompass a wide range of the identified radionuclides. Radium, radon, and corresponding decay products are not covered in the internal dose guidance in any detail, although it is identified as a major component in the Tank Farm source term. Guidance on assessing intakes of Sr-90 and accelerator gaseous activation products, such as N-13 and O-15, is not provided, although there are indications that these make up significant sources at the site. There is no discussion on the contamination levels (air and surface contamination) that could have been involved with exposures at the site. Radiological controls such as source containment, air monitoring data,

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respiratory protection usage, and surface contamination monitoring, and the changes in these as the site progressed, are not covered in the TBDs.

There is a lack of site-specific guidance on determining parameters to be used in calculating internal doses, including guidance to assess internal doses from special forms of tritium [metal tritides (MTs) and organically bound tritium] and high-fired plutonium that may have been used at the site. SC&A acknowledges, however, that generic guidance has been issued for these two issues since the issuance of the LLNL TBDs (i.e., OTIB-0066 (ORAUT 2007g) for tritium compounds, and OTIB-0049 (ORAUT 2007b) for high-fired plutonium. These generic guidance documents discuss methods on adjusting dose; however, no discussion is provided in the TBDs on where and when to identify these forms, and when they may be involved in a claimant's exposure. With no mention in the TBDs, it could be incorrectly construed that these source terms do not exist at the site.

The Occupational External Dose TBD (Thomas and Szalinski 2007) provided some general information concerning external doses, and an overall view of dosimetry at the LLNL during the years 1952–present; however, it is seriously lacking in detail and LLNL site-specific information. The TBD relies extensively on other generic documents applicable to the U.S. Department of Energy (DOE)-wide complex, and does not develop the data and issues specifically related to the conditions at the LLNL, Site 300, and other locations where LLNL workers were exposed. The TBD does not make sufficient use of the material and data developed by LLNL researchers; many of these noted authors have published numerous articles concerning radiation fields and dosimetry at LLNL.

The TBD lacks details concerning badging policies that are needed to determine the adequacy of the recorded doses, for both beta/photon and neutron radiation. The methods used to select workers for badging affect both the validity of the recorded data for monitored workers and its use in coworker models for unmonitored workers. It does not contain any dose data analysis, such as dose readings by year, corrections to dosimetry readings, number of readings and range of doses per year, etc., that is necessary to assess the adequacy of the dose records. The TBD also does not provide sufficient dosimetry information and radiation field characterization to evaluate the accuracy of the recorded doses. Some details concerning the calibration, response functions, mixed-fields, and other pertinent dosimetry parameters during the history of LLNL are needed.

Neutron dose information and data is especially lacking in the External Dose TBD. Because of the known shortcomings of Eastman Kodak Nuclear Track Film Type A (NTA) film for determination of neutron dose during the time period 1952–1969, the TBD recommends using the neutron-to-photon ratio (n/p) method to determine neutron doses. After a very brief discussion of the lack of neutron flux information at LLNL, it recommends using an n/p value of 1.0 derived from a Savannah River Site (SRS) study (part of which was taken from a Hanford study). There are no comparative studies, or technical investigations, provided to support using one n/p value derived from another site to cover the time period 1952–1969 for all operations at LLNL.

The in-depth development of important areas necessary to evaluate the adequacy of monitoring, dosimetry response, dose records, and other related issues is not available in the present TBD.

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This lack of detail is inconsistent with other site profile external dose TBDs, and the present External Dose TBD would require extensive revision to meet the needs of dose reconstruction.

The LLNL Occupational Medical TBD does not acknowledge and address the issue that little documentation exists to validate x-ray protocols and equipment maintenance and upkeep records prior to 1960, which can contribute greatly to the dose to the chest and other organs. There is no other information presented on such aspects as screens used, grids, film types, and changes in developing parameters. The dose conversion factors (DCFs) are derived from the International Commission on Radiological Protection (ICRP) Publication 34 (ICRP 1982) and are not comparable, therefore, in terms of beam quality, which would vary from unit to unit. Dose estimations derived from ICRP 1982 and the National Council on Radiation Protection and Measurements (NCRP) Report 102 (NCRP 1989) would not be reflective of actual equipment and protocols in use at LLNL during 1952–1960. The TBD does little to reasonably document the variety of medical occupational exposures and type of routine maintenance performed on the x-ray units up until 1960.

With respect to potential use of photofluorography (PFG) units at LLNL, SC&A believes a random sampling of only seven individual medical records to be insufficient to rule out PFG use at LLNL. The TBD provides no substantive documentation that PFG units were not used at that site from 1952–1960.

The LLNL Occupational Environmental TBD is incomplete, in that no method for assignment of internal dose from environmental sources for alpha- and beta-emitting radionuclides is available prior to 1961, and for tritium prior to 1972. Both materials were handled prior to the periods above. The radionuclides of concern in the TBD do not encompass radionuclides handled, particularly at Site 300. In addition, potential exposure from resuspension of soil is not included in the TBD.

Consideration of classified records should be included during subsequent revisions to the TBD. (Such consideration is not apparent in the current site profile). Information relevant to the site description, external monitoring, internal monitoring, and environmental data are contained in these records. General types of information include information on plutonium, tritium, and transuranium element handling. More detailed descriptions are available for the Atomic Vapor Laser Separation (AVLIS) program, Site 300 operations, and weapons testing. Also included in the records set is information on radiological incidents (LLNL 2006).

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

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

1.1 SUMMARY OF FINDINGS

Finding 1: Dose estimation for LLNL personnel assigned to weapons testing has not been adequately considered. Exposure conditions related to LLNL personnel participation in weapons and safety testing, and subcritical or reactor experiments have not been considered in the LLNL site profile. This involves numerous LLNL-sponsored nuclear weapons tests, including atmospheric, underwater, and underground testing in the U.S. and at PPG. Hundreds of personnel were involved in weapons testing and the Plowshare program. The significance and potential dose contribution due to LLNL personnel participation in testing has not been considered in the site profile, which is of particular concern for those test sites without existing TBDs (e.g., Amchitka, Hattiesburg, PPG, etc.). NTS eventually became the repository for the PPG and NTS dosimetry results; however, dose records or evidence that they have been requested is not available for all claimants. There is no apparent explanation provided for the benefit of the dose reconstructor on when and how doses from testing should be considered. Scientists and support personnel were responsible for re-entries to collect diagnostic equipment, cloud sampling after atmospheric tests, and processing of core and air filter samples. They worked side by side with workers in Alaska, at the NTS during atmospheric testing, and at PPG during underwater and atmospheric testing. NIOSH has identified problems with dose reconstruction for both NTS and PPG. The TBD does not provide background information and guidance on how to assess potential missed dose for exposure during weapons tests, subcriticality test shots and experiments, and the Plowshare program at testing sites across the United States. There is no information on how dose reconstruction issues previously identified at the testing sites (e.g., from past respective site profile and Special Exposure Cohort (SEC) reviews) will be addressed.

Finding 2: Inadequate consideration has been given in the site profile to potential exposure received at Site 300. The site profile is incomplete in its description of activities occurring at Site 300 and the potential radiological exposure conditions associated with these activities. Minimal dose reconstruction guidance is provided for internal and environmental occupational dose. The assumption of semi-annual bioassay monitoring is in conflict with information provided by former Site 300 employees and, in some cases, results available in dosimetry files and electronic dosimetry databases. The LLNL Site Profile indicates that the sources of radiation exposure at Site 300 include accelerators, DU, activation products from accelerators, tritium, and radiography sources when in use. Batzel (1976b) indicated that the guidelines allowed for experiments with natural uranium, DU, natural thorium, tritium, and beryllium. Sewell (1959) specifically authorized the thorium hydrodynamics program at Site 300 in 1959. No method for assessment of environmental dose from alpha emitters and tritium is available prior to 1961 and 1972, respectively. Potential extremity exposures may have occurred during hand contact with thorium and thorium alloy. An evaluation of non-hydroshot activities at Site 300 is minimally covered in the TBD, although workers were potentially exposed as a part of these activities. Further evaluation of the implemented monitoring for this area and its adequacy for the radionuclides involved in tests is necessary. Varying levels of personal protective equipment (PPE) were worn and bioassay was not routine, according to employees interviewed. In some cases, no protective clothing and/or respirators were used, and it is important to establish when this occurred. The work activities at the site appear to have had the potential for internal exposure, with some doubt that any bioassays were taken for monitoring such exposure.

Finding 3: Completeness, accuracy, and availability of data used in dose reconstruction, and as a basis for the internal coworker approach, not adequately addressed in the TBD. Information available for dose reconstruction, especially for those involved in testing and special projects, is limited, inadequate, and sometimes not available. There are major issues with verifying the accuracy and usefulness of the data in MAPPER used for the coworker internal dose assessment method. Regarding the MAPPER database, LLNL staff members have indicated that some bioassays cannot be confidently associated with a specific person, and there are ambiguities in some analytes reported. These LLNL staff members indicated that large negative results are included for later periods, letters in the sample type column do not always indicate whether the sample was urine or fecal, and overall, that sample volume and mass must be interpreted carefully. There is very little discussion in the TBD about the quality of the earlier data (1950s–1960s). With the inconsistencies inherent in MAPPER, the use of these data for the internal dose coworker model is suspect and needs to be evaluated. During SC&A's review of classified documents, additional bioassay results were discovered that lead to questions regarding the adequacy of information currently being provided in the claimant files. These additional bioassay results found in classified records, not available for the dose reconstructor's use, could have an important effect on dose reconstruction of the individual claimant's dose. In light of these shortcomings, the verification process for determining the completeness and consistency of the internal dosimetry information provided in hard copy to dose reconstructors by the site needs to be addressed.

Finding 4: **The Occupational Internal Dose TBD (Berger and Szalinski 2005) has given inadequate consideration for the impact to worker dose from secondary radionuclides**. Numerous radionuclides were handled at LLNL, ranging from microcurie to curie quantities. These have included radium, Th-228, Th-232, Am-241, U-233, Cm-244, C-252, Pu-238, C-14, Na-22, P-32, S-35, I-125, I-131, Sr-90, N-13, and O-15, along with other fission products and activation products. Much of the bioassay data in the database are identified as "gross alpha" and "gross beta" results, and NIOSH has not identified which, if any, of these secondary radionuclides may be associated with these data. NIOSH has commented that the next revision of the Internal Dose TBD will contain guidance on the interpretation of gross alpha, gross beta, and fission product bioassay results. NIOSH needs to determine if there are potential exposures to these radionuclides that cannot be reconstructed accurately, due to inadequacies with the available radionuclide-specific information. These may be similar to the inadequacies cited in NIOSH's SEC evaluation report for Los Alamos National Laboratory (LANL) (NIOSH 2007). Radium is not identified (DOE 2004) as being used in any buildings or projects to a great extent; however, there is evidence that it may have been present at the site in some abundance.

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Exposure to a number of these radionuclides was not given adequate or, in some cases, any consideration in the internal dosimetry TBD, although some are listed as facility-specific radionuclides handled in particular technical areas.

Finding 5: There is limited guidance on the interpretation of bioassay data for intakes of tritium, metal tritides, or organically bound tritium. While OTIB-0066 (ORAUT 2007g) was issued while the SC&A review was underway, and provided generic guidance on the calculation of dose from intakes of special tritium compounds, it only partially addresses some of the issues discussed below. According to the Site Description TBD (ORAUT-TKBS-0035-2), Building 331 (Hydrogen/Tritium Research Facility) had the bulk of the tritium inventory in elemental form or metal hydrides. Metal hydrides of tritium are special chemical forms for tritium, and are also called metal tritides (MT). These MTs are somewhat insoluble forms of tritium compounds (Inkret et al. 1999, Cheng et al. 1997) that do not exhibit similar biokinetic behavior to the more common forms of tritium, such as tritiated water (HTO) or elemental tritium. Tritium from MTs does not enter the systemic compartment as quickly as HTO after inhalation and, therefore, the interpretation of tritium urine bioassay data cannot be treated with standard tritium excretion models (McConville and Woods 1995). Due to being relatively insoluble, inhaled MTs deliver the highest component of dose contribution to the lungs. Tritium from these particles also can convert to organically bound tritium forms (OBTs) from contact with lung tissue and further complicate the metabolic process (DOE 2004). OBTs were not discussed in the TBD. It has been determined that OBTs cause a significantly larger dose than tritium, more routinely found in the form of tritiated water (HTO) (DOE 2004). Not addressing MTs or OBTs could lead to underestimating doses. Bounding techniques proposed in OTIB-0066 (ORAUT 2007g) cannot be effectively developed and applied without some basic understanding of the compounds handled and the extent to which individuals were exposed.

Finding 6: The Internal Dose TBD does not identify the possible chemical forms of the airborne radionuclides to which workers are exposed. The TBD is lacking information that allows for the identification of the possible chemical forms of the airborne radionuclides to which workers could have been exposed. This is needed in order to give guidance on the solubility (absorption) class to use (F, M, or S) for inhalation and intake dose assessment. The Occupational Internal Dose TBD (Berger and Szalinski 2005) states, "Other variables such as particle sizes and clearance classes can be readily reconstructed from historical records." No specific references are made to these historical records. There is no discussion on the potential for exposures to very insoluble and slowly absorbed high-fired plutonium. NIOSH has recently issued OTIB-0049 (ORAUT 2007b), which provides some assistance to the dose reconstructor with respect to high-fired plutonium; however, the LLNL TBDs do not identify the potential for this existing at the site.

Finding 7: The Internal Dose TBD has not adequately identified and reviewed applicable bioassay frequencies and detection levels. In many cases, the information given for bioassay frequencies and detection levels is not useful, because of inaccuracy or lack of information. In the table showing bioassay frequencies, several in-vitro bioassays lack identification of radionuclides analyzed, and the frequency of whole-body counts (WBCs) for a period is missing. In addition, the table showing bioassay detection levels include values for in-vitro bioassay that disagree with historical site documents. Doses may not be calculated accurately without this information, and may not be claimant favorable. While the collective origins of these apparent discrepancies are not clear, more complete and validated information should be made available to dose reconstructors.

Finding 8: No approaches are provided for determining the internal doses to workers that were unmonitored or inadequately monitored for plutonium, tritium, or other radionuclides. The *Internal Dosimetry Coworker Data for Lawrence Livermore National Laboratory*, OTIB-0065 (ORAUT 2007e), provides an approach for determining internal dose only for uranium intakes by unmonitored or inadequately monitored workers, but does not address plutonium, tritium, or other radionuclides. This includes workers that were exposed to radionuclides prior to any bioassay monitoring (appears to be <1960) and those not monitored or inadequately monitored after applicable bioassay became available. If additional guidance is available from other sources, it is not referenced in the TBD.

Finding 9: Criteria for Badging not sufficiently Defined in the External Dose TBD. LLNL is a large, complex site that has been in operation for over 50 years, with workers occupying several physical locations (LLNL proper, Site 300, PPG, and NTS). The Occupational External Dose TBD states that the personnel dosimetry records are generally available for all periods at LLNL for workers that had the potential for exposure to radiation (Thomas and Szalinski 2007, pg. 7). However, the TBD does not sufficiently define what workers were monitored, and what criteria were used to select those workers to allow determination of the adequacy of badging through the years. The use of the criterion that those with "significant potential for radiation exposure" were monitored could have left some workers unmonitored that, by later knowledge and standards, should have been monitored. For example, Nolan (1958) states that changes in the badging program of 1958 "…has brought to light exposures to personnel that were not being recorded and exposures of which we were unaware."

The LLNL badging criterion for beta/photon radiation during the period 1952–1957 was that those workers with significant potential for radiation exposure were badged. Then in 1958, it was decided to provide beta/photon badges to all workers entering the site, regardless of exposure potential, as discussed in the External Dose TBD. This total badging policy is somewhat different than the criterion that is listed in Table 6-5 on page 14 of the TBD, where for 1952–present, it states that "All employees **with significant measurable exposure potential** were monitored continuously" [emphasis added]. This criterion would not necessarily include all workers entering the site. The latter statement is supported by gaps in monitoring, as noted on page 15 and annotation [7] of the TBD.

The badging policy for neutron monitoring is even less defined than for beta/photons. It is not evident from the TBD that there were technically defined monitoring policies for neutrons, to ensure adequate external dose monitoring. Apparently, the badging policy for neutrons has been the same from 1952 to the present. This policy is that neutron badges are provided to workers where significant neutron exposures are possible, as noted on page 10 of the TBD. No definition of "significant" has been provided. Additionally, the TBD concludes that if a worker was not badged for neutrons, there is no potential for neutron exposure. In view of the fact that so little is known about neutron badging policies and details concerning neutron fields (especially during the early years), there is no technical justification for concluding that unmonitored workers could not have been exposed to neutrons (Nolan 1958). This concern applies to both TLD neutron monitoring and when the dose reconstructor is to assign neutron dose using n/p values when NTA films were used.

Finding 10: Insufficient Dose Data Analysis is Provided in the External Dose TBD. The External Dose TBD (Thomas and Szalinski 2007) does not provide the dose data analysis that is necessary to evaluate the adequacy of the dose data for the workers. It is stated that 95% of the workers were badged during 1952–1957. However, it is not clear from the TBD if this includes subcontractor, temporary workers, and the like. Additionally, no breakdown of the number of badges and workers by year was provided. It does not state if 95% of the workers were badged for beta/photon and neutrons, or just beta/photon. There are also no analyses of the recorded doses, such as maximum/means/minimum, and the number of zeros/blanks that occurred on a yearly basis.

This type of data analysis should be presented and discussed in the site-specific Occupational External Dose TBD, or a site-related OTIB to determine if the workers were adequately monitored, and if there were any weak points in the monitoring programs that could result in unmonitored doses. Additionally, this information is necessary to verify any coworker model and/or data tables developed to assign dose to unmonitored workers, or to fill in gaps in monitored workers' dose records.

Dose data analysis is especially important concerning neutron monitoring, because this type of information is necessary to (1) evaluate the adequacy of TLD neutron monitoring during 1970–present, and (2) to analyze the sufficiency of neutron badging during 1952–1969, because the dose reconstructor will use NTA badging as a guide to determine if the worker should be assigned neutron dose using the n/p method. Additionally, information concerning n/p data (or alternate methods) that will be used for assigning neutron doses during the period that NTA film was used needs to be provided.

Finding 11: Lack of Dosimetry Characterization Information Provided in the External Dose TBD. Throughout the Occupational External Dose TBD (Thomas and Szalinski 2007), the dose data records are presented as containing the correct dose received by the worker; however, a number of technical issues are not considered in this assumption. Lawrence Berkeley National Laboratory (LBNL) provided the dosimetry from 1952–1955; however, no details of calibration, response as a function of energy, geometry, mixed fields, or other pertinent parameters were provided. This was still an era when film dosimetry was being developed and some problems existed in dosimetry. Additionally, these response functions were not covered after 1955, when LLNL provided the dosimetry. These concerns apply to both beta/photon film and the derivation of applicable n/p values for assigning neutron dose instead of using NTA film results. Page 8 of the TBD (Thomas and Szalinski 2007) states that the dose reconstructor can compare earlier dosimetry systems to current systems to evaluate their performance. However, this is an area that should be addressed in detail in the TBD, and not a task relegated to the dose reconstructor. In addition to adjustment factors, dose uncertainties are not sufficiently addressed in the TBD.

The recommendation on page 14 of the TBD that no adjustments be made to the beta/photon dose readings would indicate that the dosimetry system measured the correct external dose

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within a few percent for all radiation fields at all locations for the entire time period of 1952 to the present. This is most likely not the case, especially during the 1950s and 1960s.

The only adjustment to the neutron doses was the recommendation on page 14 of the TBD, which was to multiply the recorded dose by a factor of 1.91 to account for the ICRP 60 (ICRP 1990) weighting factors. There are a number of areas concerning neutron dosimetry that are lacking in the present TBD and need to be addressed. These areas include neutron energy spectra, derivation/verification of n/p values; TLD and CR-39 response to different neutron energy spectra at LLNL; and calibration details. The very important task of deriving appropriate n/p values for LLNL was not provided in the TBD; instead, the results of a study done at the SRS (Scalsky 2005) were recommended. (The study at SRS was dependent on a study done at the Hanford site). The TBD recommends using the SRS n/p geometric mean (GM) value of 1.0, with geometric standard deviation (GSD) of 3.0, and an upper 95th percentile of 6.1. This value was stated without any documented analysis, supportive evidence, or determination of compatibility of neutron exposures between SRS and/or Hanford and LLNL. LLNL was one of the DOE centers for dosimetry development. From the available LLNL documents and publications (for example, Hankins 1975, Hankins 1976, and Slaughter and Reuppel 1977), it appears that much more pertinent information could be included in the TBD to assist in evaluating neutron fields and external doses to workers.

Finding 12: Lack of an External Dose Coworker Model. The Occupational External Dose TBD (Thomas and Szalinski 2007) does not provide any coworker data/model/tables for use by the dose reconstructor in assigning doses to unmonitored workers, except to refer the dose reconstructor to Table 6E-2 in the LANL TBD (Widner 2005). Also, no TIB has been issued to date that covers unmonitored LLNL workers' external dose assignments using coworker data. This applies to beta, photon, and neutron radiation doses. Additionally, for an unmonitored worker (who has been deemed to have a low potential for exposure), it is recommended in the TBD that only the environmental dose be assigned. This would result in zero doses being assigned from any other radiation exposures, and could result in an underestimate of total dose. The TBD needs to be expanded to include, or reference made to a TIB that contains, detailed information that can assist the dose reconstructor in assigning technically sound external doses to undermonitored or unmonitored workers at LLNL.

1.2 OPPORTUNITIES FOR IMPROVEMENT

(1) In the Occupational Internal Dose TBD (Berger and Szalinski 2005, Section 5.3.2, pg. 19), there are conflicting statements on how sampling was done. The first paragraph states the following:

> *The practice of offsite collection of samples, which takes place approximately 24 to 48 hours after leaving the site, not only minimizes the possibility of sample cross-contamination, but also ensures sample collection after the transfer of the rapid clearance component. Some LLNL employees might have been asked to submit samples after 1 or 2 days off from work; there could be notation of that instruction on the analytical record.*

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The next paragraph states the following:

> *LLNL typically collected urine samples in the workplace, usually on a Wednesday. Therefore, contamination of samples from worker's hands or clothing cannot be ruled out as a contributor to any given result.*

The first paragraph may have been discussing radionuclides other than tritium and the second paragraph was possibly about tritium, but this, or any other distinction, is not specified. Therefore, the section is confusing, apparently contradictory, and needs to be clarified to help the internal dose reconstructor.

(2) In Section 5.3.2 of the Occupational Internal Dose TBD (Berger and Szalinski 2005), it states that, "Uncertainties associated with bioassay measurements were not stated in the records." Table 5-6 in this section, Bioassay record codes, states that column numbers 50–51 have the "Error," which is "One standard deviation as a percentage of the result." Therefore, it appears that the bioassay record could have the one standard deviation uncertainty expressed as a percent of the result value, which would allow the uncertainty to be calculated by multiplying the fractional value of the percent by the result.

(3) In Section 5.3.2 (Berger and Szalinski 2005), it states that, "If a data set shows an unusually high urinalysis result for a given radionuclide, and if follow-up samples were not consistent with the high result, dose reconstructors can consider the high result an outlier and disregard it." However, if the result is not obviously an outlier, it is claimant-favorable to assume the result is real. This guidance on identifying a high result as an "outlier" appears to be something that should have come from general guidance that is applicable to most, if not all, internal dose reconstructions done by NIOSH. It is very brief and not detailed enough guidance to ensure a dose reconstructor will perform consistent and claimant-favorable intake assessments. If there is more detailed guidance in a general bioassay interpretation procedure applicable to this data, then citing the reference (and possibly discussing it in more detail) is necessary. The above discussion is applicable to all parts of the TBD that address guidance from general procedures that are applicable to more than just LLNL or any other specific site. NIOSH should compare statements in the TBD to their recent generic guidance document for internal dose reconstruction, OTIB-0060 (ORAUT 2007c), and revise as necessary.

(4) The TBD (Berger and Szalinski 2005) does not cite ICRP Publication 23, *Reference Man* (ICRP 1974), in the text, but it lists the document in the references. This publication has been updated and the TBD should list the replacement in the references (ICRP 2002). The update has larger volumes for daily urine excretion (1.6 liters/day for men, and 1.2 liters/day for women), and this is needed when converting urine bioassay radionuclide concentrations (pCi/liter, μg/liter, etc.) accurately to 24-hour sample activity results. If NIOSH does not agree that these updated urine excretion volumes are applicable to this dose reconstruction, it should be discussed.

(5) The current version of the LLNL Occupational Environmental Dose TBD, ORAUT-TKBS-0035-4 (Thomas 2005), was published without air monitoring data prior to 1961

and tritium air monitoring data prior to 1972. The TBD (Thomas 2005, pg. 15) states that, "Efforts are currently in progress to develop estimated intakes for these missed periods and may be presented in a future revision of this TBD." Methods for exposure assessment should be developed for the early years.

(6) In the Occupational Medical Dose TBD (Turner 2005), NIOSH may need to focus additional attention to finding other sources that might shed more light on aspects such as operating parameters, screens used, film types, filtration used, number of retakes to produce a quality image, maintenance regimens, type and amount of collimation, and development parameters to better determine if these factors may have resulted in a greater uncertainty than envisioned in the TBD and, therefore, may have resulted in a greater dose per x-ray than is assumed in NCRP 1989 tables.

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2.0 SCOPE AND INTRODUCTION

The review of the LLNL Site Profile was conducted during October 2006–June 2007 by a team of SC&A health physicists and technical personnel. Given the classified nature of some of the records for which access was needed, arrangements were made through the DOE for special clearances, as well as declassification reviews of notes taken and interviews conducted with site personnel and former workers. Two members of the SC&A team hold “Q” clearances that permitted unencumbered access for this review.

Two team members also participated in the NTS site profile review conducted by SC&A in 2005, from which relevant issues were derived that apply to LLNL personnel involved with nuclear testing activities at NTS and other such sites. Likewise, several members of the team conducted the site profile review of LANL in 2006; a number of dosimetry and records issues from that site have relevance to LLNL.

SC&A understands that site profiles are living documents, which are revised, refined, and supplemented with TIBs as required to help dose reconstructors. Site profiles are not intended to be prescriptive or necessarily complete in terms of addressing every possible issue that may be relevant to a given dose reconstruction. It is recognized that NIOSH has data capture activities ongoing at LLNL while this review is underway. Likewise, additional guidance documents were being issued that while not reflected yet in the current LLNL site profile TBDs, would serve to mitigate some of the gaps and issues raised in this report (where appropriate, these recent issuances have been so noted).

2.1 REVIEW SCOPE

Under EEOICPA and federal regulations defined in Title 42, Part 82, *Methods for Radiation Dose Reconstruction Under the Energy Employees Occupational Illness Compensation Program*, of the *Code of Federal Regulations* (42 CFR Part 82), the Advisory Board is mandated to conduct an independent review of the methods and procedures used by NIOSH and its contractors for dose reconstruction. As a contractor to the Advisory Board, SC&A has been charged under Task 1 to support the Board in this effort by independently evaluating a select number of site profiles that correspond to specific facilities at which energy employees worked and were exposed to ionizing radiation.

This report provides a review of the following six documents related to historical occupational exposures at LLNL:

ORAUT-TKBS-0035-1, *Technical Basis Document for Lawrence Livermore National Laboratory – Introduction Rev. 00 PC-1*, September 12, 2005 (Maisler 2005a)

ORAUT-TKBS-0035-2, *Technical Basis Document for Lawrence Livermore National Laboratory – Site Description Rev. 00 PC-1*, October 26, 2005 (Maisler 2005b)

ORAUT-TKBS-0035-3, *Technical Basis Document for Lawrence Livermore National Laboratory – Occupational Medical Dose Rev. 01 PC-1*, October 26, 2005 (Turner 2005)

ORAUT-TKBS-0035-4, *Technical Basis Document for Lawrence Livermore National Laboratory – Occupational Environmental Dose Rev. 00 PC-1*, November 18, 2005 (Thomas 2005)

ORAUT-TKBS-0035-5, *Technical Basis Document for Lawrence Livermore National Laboratory – Occupational Internal Dose Rev. 00*, October 10, 2005 (Berger and Szalinski 2005)

ORAUT-TKBS-0035-6, *Technical Basis Document for Lawrence Livermore National Laboratory – Occupational External Dose Rev. 01, April 26, 2007* (Thomas and Szalinski 2007)

These documents are supplemented by TIBs, which provide additional guidance to the dose reconstructor. A complete list of these documents is available in Attachment 1.

Implementation guidance is also provided by "workbooks" developed by NIOSH for selected sites to provide more definitive direction to the dose reconstructors on how to interpret and apply TBDs, as well as other available information. The LLNL-specific workbooks have been evaluated by SC&A under a separate task (Task 3) and are included in evaluations being submitted under that task.

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

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

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

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

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

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

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

2.2 REVIEW APPROACH

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

All review comments apply to either Rev. 00 or Rev. 00 PC-1 versions of the LLNL TBDs, which are the most recent published versions, with the exception of the Occupational External Dose TBD, which is available as Rev. 01. SC&A is aware of ongoing information-gathering activities by NIOSH at LLNL to support a revision of the existing TBDs.

Attachment 1 is a list of the LLNL TBDs and the supporting TIBs that were reviewed during the SC&A site profile review.

Site expert interviews were conducted to help SC&A obtain a comprehensive understanding of the radiation protection program, site operations, and historic exposure experience. Attachment 2 provides summaries of the interviews conducted by SC&A during the course of this review. The interviewees included current and former staff from the LLNL Hazards Control division, and were conducted by Joseph Fitzgerald (SC&A/Saliant Inc.), Kathryn Robertson-DeMers (SC&A/Saliant Inc.), and William James (SC&A/Saliant Inc.) from April 14–19, 2007.

On November 9, 2006, SC&A sent questions to NIOSH as part of its evaluation of the TBDs. These questions are reproduced in Attachment 3. NIOSH and ORAUT provided written responses to these questions on December 6, 2006, which are provided in Attachment 3, along with the NIOSH responses. Additional questions stemming from the review were submitted by SC&A to NIOSH on June 8, 2007, with a NIOSH/ORAUT response received on June 29, 2007. These additional questions and the corresponding responses are also provided in Attachment 3.

Attachment 4 provides a listing of the LLNL-sponsored atmospheric weapons tests, underwater and underground weapons tests, and special LLNL projects related to these tests.

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2.3 REPORT ORGANIZATION

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

(1) Executive Summary
(2) Scope and Introduction
(3) Assessment Criteria and Method
(4) Site Profile Strengths
(5) Vertical Issues and Secondary Issues
(6) Overall Adequacy of the LLNL Site Profile as a Basis for Dose Reconstruction.

Based on the issues raised in each of these sections, SC&A prepared a list of findings, which are provided in the Executive Summary. Issues are designated as findings if SC&A believes that they represent deficiencies in the TBD that need to be corrected, and which have the potential to have a substantial impact on at least some dose reconstructions. Issues can also be designated as Secondary Issues if they simply raise questions, which, if addressed, would further improve the TBDs and may possibly reveal deficiencies that will need to be addressed in future revisions of the TBDs.

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

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

- Dose estimates not developed for unmonitored LLNL personnel at the atmospheric and underground nuclear testing, particularly for potential internal intakes

- Inadequate characterization of radiological hazards at Site 300

- Lack of coverage of waste management, and Decontamination and Decommissioning (D&D) activities

- Verification of the accuracy and usefulness of the data in the bioassay electronic database (MAPPER, not identified by this name in the TBD)

- Lack information concerning sufficiency of data for early worker dose reconstructions

- Inadequate consideration of missed dose to other radionuclides; this exposure was not as well characterized or monitored

- Exposure to tritium compounds was not fully addressed in the TBDs

- Insufficient investigation and determination of alternate dose assignment methodology to replace NTA film dose-of-record results

- Need to identify chemical forms of radionuclides, in order to provide guidance on which solubility (absorption) class to use (F, M, or S) for inhalation and intake dose assessment

- Lack of information on incidents that could have caused significant intakes of radionuclides

- Need for specific guidance on parameter choice and assumptions for intake and dose assessments

- Lack of data, particularly in the early years, of the type of x-ray equipment used, the beam quality, and the x-ray protocols that impact the DCFs

- Lack of data to properly document the frequency of chest x-rays and other occupationally related x-rays.

SC&A believes that these important issues need to be effectively dealt with in any upcoming revisions to the LLNL Site Profile TBDs, in order to ensure that the most scientifically valid and claimant-favorable dose reconstructions can be effectively conducted in areas where these data gaps exist.

3.0 ASSESSMENT CRITERIA AND METHODS

SC&A is charged with evaluating the approach set forth in the site profiles that is used in the individual dose reconstruction process. These documents are reviewed 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 LLNL Site Profile, supporting TIBs, and dose reconstruction worksheets; 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 identifies assumptions by NIOSH that give the benefit of the doubt to the claimant.

3.1.1 Objective 1: Completeness of Data Sources

SC&A reviewed the site profile with respect to Objective 1, which requires SC&A to identify principal sources of data and information that are applicable to the development of the site profile. The two elements examined under this objective include (1) determining if the site profile made use of available data considered relevant and significant to the dose reconstruction, and (2) investigating whether other relevant/significant sources are available, but were not used in the development of the site profile. For example, if data are available in site technical reports or other available site documents for particular processes, and if the TBDs have not taken into consideration these data where 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 TBDs, was evaluated to determine the relevance of the data collected by NIOSH to the development of the site profile. Additionally, SC&A evaluated records publicly available relating to the LLNL site and records provided by site experts.

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 LLNL. 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.

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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 LLNL TBD was compared to several of the sites already reviewed by SC&A. The results of this comparison are provided in Section 6.1.4.

3.1.5 Objective 5: Regulatory Compliance

SC&A reviewed the site profile with respect to Objective 5, which requires SC&A to evaluate the degree to which the site profile complies with stated policy and directives contained in 42 CFR Part 82. In addition, SC&A evaluated the TBD for adherence to general quality assurance policies and procedures utilized for the performance of dose reconstructions.
In order to place the above objectives into the proper context as they pertain to the site profile, it is important to briefly review key elements of the dose reconstruction process, as specified in 42 CFR Part 82. Federal regulations specify that a dose reconstruction can be broadly placed into one of three discrete categories. These three categories differ greatly in terms of their dependence on and the completeness of available dose data, as well as on the accuracy/uncertainty of data.

Category 1: Least challenged by any deficiencies in available dose/monitoring data are dose reconstructions for which even a partial assessment (or minimized dose(s)) corresponds to a probability of causation (POC) value in excess of 50%, and assures compensability to the claimant. Such partial/incomplete dose reconstructions with a POC greater than 50% may, in some cases, involve only a limited amount of external or internal data. In extreme cases, even a total absence of a positive measurement may suffice for an assigned organ dose that results in a POC greater than 50%. For this reason, dose reconstructions 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 to not compensate a claim.

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

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

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

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

ORAUT-TKBS-0035-1, Rev. 00, PC-1, *Technical Basis Document for Lawrence Livermore National Laboratory – Introduction* (Maisler 2005a), explains the purpose and the scope of the site profile. SC&A was attentive to this section because it explains the role of each TBD in support of the dose reconstruction process. During the course of its review, SC&A was cognizant of the fact that the site profile is not required by the EEOICPA or by 42 CFR Part 82, which implements the statute. Site profiles were developed by NIOSH as a resource to the dose reconstructors for identifying site-specific practices, parameter values, and factors that are relevant to dose reconstruction. Based on information provided by NIOSH personnel, SC&A understands that site profiles are living documents, which are revised, refined, and supplemented with TIBs as required to help dose reconstructors. Site profiles are not intended to be prescriptive or necessarily complete in terms of addressing every possible issue that may be relevant to a given dose reconstruction. Hence, the introduction helps in framing the scope of the site profile. As will be discussed later in this report, NIOSH may want to include additional qualifying information in the introduction to this and other site profiles describing the dose reconstruction issues that are not explicitly addressed by a given site profile.

ORAUT-TKBS-0035-2, Rev. 00 PC-1, *Technical Basis Document for Lawrence Livermore National Laboratory – Site Description*, (Maisler 2005b), is an important document because it provides a description of the facilities, processes, and historical information that serve as the underpinning for subsequent LLNL TBDs. For a laboratory such as LLNL with its diverse and complex activities, the identification of radiologically significant operations assures that important source terms are accounted for and addressed in the site profile.

ORAUT-TKBS-0035-3, Rev. 01 PC-1, *Technical Basis Document for Lawrence Livermore National Laboratory – Occupational Medical Dose*, (Turner 2005), provides an overview of the sources, types of exposure, and the frequency of exams that workers potentially received. SC&A reviewed this section for technical adequacy and consistency with other NIOSH procedures, and compared these with other site profiles.

ORAUT-TKBS-0035-4, Rev. 00 PC-1, *Technical Basis Document for Lawrence Livermore National Laboratory – Occupational Environmental Dose*, (Thomas 2005), 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. SC&A's review also included particular attention to Site 300 releases, given the extensive history of outdoor hydroshot and other radiological design studies.

ORAUT-TKBS-0035-5, Rev. 00, *Technical Basis Document for Lawrence Livermore National Laboratory – Occupational Internal Dose*, (Berger and Szalinski 2005), presents background information and guidance to dose reconstructors for deriving occupational internal doses to workers. This section was reviewed with respect to background information and guidance regarding the types, mixes, and chemical forms of the radionuclides that may have been inhaled or ingested by the workers; the recommended assumptions for use in reconstructing internal doses based on the available types of bioassay data (in vivo and in vitro); the methods recommended for use in the reconstruction of missed internal dose; and the methods recommended for characterizing uncertainty in the reconstructed internal doses.

ORAUT-TKBS-0035-6, Rev. 01, *Technical Basis Document for Lawrence Livermore National Laboratory – Occupational External Dose*, (Thomas and Szalinski 2007), presents background information and guidance to dose reconstructors for deriving occupational external doses to workers. This section was reviewed with respect to background information and guidance regarding the different types of external radiation (i.e., gamma, beta, and neutron) and the energy distribution of this radiation to which the workers may have been exposed. SC&A also reviewed the recommendations for converting external dosimetry data to organ-specific doses, the methods recommended for use in reconstruction of missed external doses, and the methods recommended for characterizing uncertainty in the reconstructed external doses.

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

There are three levels of review for this report. First, SC&A team members reviewed the report internally. Second, SC&A senior management and editorial staff who had not participated in the preparation of this report conducted a review of this report. The report was then submitted to the NIOSH's Office of General Counsel for Privacy Act review according to previously established procedures. Finally, the draft report is submitted to the Advisory Board, with copy to NIOSH, for review and comment by the Board and NIOSH.

We anticipate that, in accordance with the procedures followed during previous site profile reviews, the report will then 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 during an issue resolution process, or if NIOSH issues revisions to the TBDs or additional TIBs, and the Advisory Board requests SC&A to review these documents.

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4.0 SITE PROFILE STRENGTHS

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

- The LLNL Occupational Medical Dose TBD (Turner 2005) has provided a good summary of the four types of x-ray machines used at LLNL in Table 3.1, and has expanded on what is known about these x-ray machines in Sections 3.4.2 through 3.4.4.

- Dosimetry methods used for beta, photon, and neutron dose monitoring were described separately, and also as a function of time and technology changes.

- The Internal Dosimetry Dose TBD has strengths in its discussions of in-vivo capability and inclusion of radionuclides in the source terms of buildings. NIOSH has done a thorough job of describing the development and capabilities of the in-vivo bioassay programs at LLNL, which includes the listing of the monitoring frequency, periods of usage, and minimum detectable activities (MDAs) for major radionuclides.

- The implementation of ORAUT-OTIB-0006, *Dose Reconstruction for Occupationally Related Diagnostic X-Ray Procedures*, Rev. 2 (ORAUT 2003b), has provided a great deal of consistency between different site profile assumptions. Incorporation of Rev. 3 PC-1 (ORAUT 2005d) of this document into dose reconstruction guidance for medical x-ray dose in the LLNL Occupational Medical Dose TBD (Turner 2005) would provide further consistency among site profiles.

- The TBDs' use of personnel monitoring data and environmental monitoring data to determine dose is consistent with the requirements outlined in 42 CFR Part 82, in that (1) where in-vivo and in-vitro analyses are available, this information is provided for use in determination of internal dose, and (2) where routine beta/gamma and neutron dosimeters are available and adequate, this information is provided for use in determination of external exposure. Where environmental measurements are available, these data are used as the basis for environmental dose.

- The TBD authors had arranged for discussions with key external and internal dosimetry personnel to support the preparation of their respective TBDs.

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5.0 VERTICAL ISSUES

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

5.1 DOSE ESTIMATION FOR LLNL PERSONNEL ASSIGNED TO WEAPONS TESTING HAS NOT BEEN ADEQUATELY CONSIDERED

The significance and potential dose contributions from LLNL personnel participation in weapons, subcritical experiments, and safety shots are not considered in the site profile. LLNL sponsored atmospheric, underwater, and underground nuclear weapons testing of their weapons designs, supported other laboratories conducting tests, conducted safety shots, and performed subcritical experiments at NTS, PPG, and other test locations. These tests started in 1953 and continued until the end of weapons testing in 1992. Attachment 4 lists the LLNL-sponsored events. In *30 Years of Technical Excellence* (LLNL 1983), the emphasis on weapons development and testing is evident:

> *Nuclear weapons R & D has consistently remained LLNL's largest program. Its direct and indirect staffing level in fiscal 1982 was 3,221 full-time positions – 47% of the Lab's operations staff. People working directly on technical aspects of weapons number about 1,400.*

The test group from the laboratory responsible for the design of the weapons [e.g., LLNL, LANL, or Sandia National Laboratory (SNL)] sent a contingent of personnel to the test sites for testing preparation, detonations, recovery of data and materials post-detonation, and support functions (including radiological safety). Operations performed by LLNL staff included device or weapons assembly, test preparation, detonation, retrieval of equipment and material after detonation, follow-up monitoring after detonation, monitoring during analysis of weapons debris, and decontamination of test sites. Rotating crews of laboratory personnel were sent to the site for tests, with a typical weapons test operation involving 100 or more personnel for a smaller test and from 400–500 for a larger test, such as a tunnel shot (see Attachment 2). During testing activities, both LANL and LLNL personnel were temporarily stationed at the NTS and PPG for extended periods of time. LLNL staff was typically sent out to PPG for periods of several weeks and were located on the island 24-hours per day. For events located in Area 12 (the tunnels) or Pahute Mesa, personnel often stayed at the Area 12 Camp at NTS, because of the rigorous schedules. There were approximately 100 individuals permanently assigned to NTS. In the cases where LANL or SNL sponsored the weapons test, a smaller complement of LLNL personnel was required to be present. Hundreds of personnel over the period of testing were involved and potentially exposed to radioactive material during these operations.

Radiological personnel were frequently deployed to test areas to assist with radiological safety problems at test sites (see Attachment 2). Responsibilities of NTS and LLNL radiological control staff were delineated by NTS and LLNL in procedures and the Test Manager's

Operational Plan. Reynolds Engineering and Electrical Company (REECo) served as a support contractor to the sponsoring laboratory, providing dosimetry and records services, and instrumentation. When individuals visited the NTS, they were asked to leave their LLNL dosimeter at home. During tests at NTS, PPG, and other test sites, dosimetry was provided by REECo (PPG and NTS) or Eberline (Tonapah, Cannikin (Amchitka), Gasbuggy (Colorado) (see Attachment 2).

Dose information for LLNL employees was sent to LLNL and the external dose data has been added to the individual personal dosimetry files. In cases where bioassay was collected for shots, these data do not appear to be integrated into the MAPPER database or the LLNL personal dosimetry file. Based on conversations with Nevada staff, records are currently being retrieved by NIOSH from the Nevada repository. A few years ago, NIOSH provided a list of LLNL employees to NTS to determine if exposure records were available for these individuals. Although there appears to be documented external exposure for those involved in testing at the NTS and PPG, there is no discussion in the TBD of when this data is to be requested and how it is to be considered in dose reconstruction. The LLNL TBD does not provide guidance on when to assume exposure as a result of test involvement, nor does it refer the dose reconstructor to the NTS TBD for Nevada exposures. Absence of records from the time spent at the testing sites forms the basis for concerns raised by workers and their advocates.

Site experts indicated that bioassay sampling was done at REECo under special conditions or in the case of incidents. If the results for REECo personnel were positive, the laboratory staff was asked to submit a bioassay sample. The data from bioassay monitoring conducted by REECo are available in records maintained by the Nevada Operations Office (NVOO). Routine bioassay sampling was not conducted for LLNL employees at the test sites, nor were workers required to submit bioassay samples in a timely manner upon return from the test site. This creates a significant potential for missed or unmonitored internal dose.

It is understood that NIOSH, under EEOICPA protocols, verifies a claimant's work location(s), including work at other Atomic Energy Commission (AEC) or DOE sites, and requests dosimetry records for these locations to facilitate dose reconstruction. It is not clear from the LLNL site profile, however, how visiting LLNL employees on testing missions were monitored. It is also unclear who was monitored and, if monitored, how their doses were integrated with their personnel dose record at LLNL. It is also unclear what status was accorded REECo monitoring data in determining dose for LLNL employees. Since REECo and/or Eberline dosimeters were used in place of LLNL dosimeters, the external dose provided by REECo, NVOO, or Eberline is subject to the same shortcomings as those documented in the *Review of the NIOSH Site Profile for the Nevada Test Site* (SCA-TR-TASK1-0006) (SC&A 2005). In brief, these issues relate to lack of neutron dose data, potential neutron exposure during atmospheric testing, angular dependence of dosimeters, and uncertain status of bomb assembly workers.

The TBD does not provide information on dose reconstructions during testing activities, nor does it refer the dose reconstructor to site profiles prepared for NTS. The Site Description TBD, ORAUT-TKBS-0035-2 (Maisler 2005b), provides limited information on LLNL's participation in testing:

> *LLNL personnel supported a variety of nuclear weapons testing from 1952 through the late 1980s. Specific information about these tests is not provided in the Site Profile. Individual exposure records should include information for personnel who traveled to the Nevada Test Site, Pacific Proving Ground, or other nuclear weapons testing locations (Alaska, Colorado, New Mexico, and Mississippi). These records should include external dosimetry results as well as bioassay that might have been performed.*

LLNL personnel worked side by side with Alaskan, REECo, and PPG workers during atmospheric, underground, and underwater testing. NIOSH has identified problems with dose reconstruction for PPG (SEC-00020, Harrison-Maples 2005) and NTS (SEC-00050, Harrison-Maples et al. 2006). The TBD does not provide background information and guidance on how to assess potential missed dose for exposure during weapons tests, subcriticality test shots and experiments, and the Plowshare program at testing sites across the U.S. There is no information on how dose reconstruction issues previously identified at the testing sites will be overcome.

In their evaluation of the feasibility of completing dose reconstruction for all employees of DOE, DOE contractors, or subcontractors employed at PPG from 1946 through 1962, NIOSH clearly indicates that workers had the potential for internal exposure (Harrison-Maples 2005):

> *The principal potential source of internal radiation doses for members of the class would have been inhalation or ingestion due to contamination caused by the fallout from the nuclear detonations.*

Furthermore,

> *Fallout associated with some of the detonations, both on the land surface and in the water, was a potential source of internal exposure. The possibility existed for inhalation and ingestion of radiological particles during a fallout event as well as exposure to re-suspended fallout remnants at some later date. Radiological particles on the land surface could potentially have been disturbed and re-suspended by wind, personnel traffic through contamination areas, construction activities disturbing contaminated soil, or by decontamination efforts, and been inhaled or ingested by personnel operating in contaminated areas* (Harrison-Maples 2005).

SEC-00020 indicates that due to lack of data, it was not feasible to perform reconstruction of internal dose from inhalation of radionuclides:

> *NIOSH finds that the external monitoring records and operational histories available are sufficient to complete external dose reconstruction for these employees, with the exception of neutron exposure, which was not fully evaluated. Existing NIOSH procedures could be used to estimate possible occupational medical exposures. However, NIOSH lacks access to source term data, bioassay or internal monitoring data to estimate internal doses associated with potential inhalation of radionuclides.*

The same potential for internal exposure also existed during the atmospheric tests at NTS. SEC-00055 (Harrison-Maples et al. 2006) further indicates that calculation of internal dose is not feasible:

> *Consequently, based on the available data, NIOSH is unable to estimate with sufficient accuracy internal exposures and resulting doses for the class of employees covered by this evaluation. The initial class for which feasibility was considered by NIOSH in response to SEC Petition SEC-00055 comprised laboratory assistants who worked at the NTS from January 27, 1951 through December 31, 1962. The basis for the infeasibility of dose reconstruction for the petitioner's specific claim was the inability of NIOSH to adequately address potential exposures associated with the changing and undefined source term during multiple atmospheric tests at the NTS. While it is very likely that individuals in the forward areas during atmospheric nuclear testing would have received exposure exceeding those of other groups of workers, NIOSH is unable to determine which workers were or were not potentially exposed to the changing radiological conditions during atmospheric nuclear testing.*

The current class definitions for PPG and NTS specify DOE or DOE contractors or subcontractors who were monitored, or should have been monitored, at PPG and NTS. Although LLNL scientists were actively involved in similar operations to those employed at PPG and NTS, it is unclear in the TBD how it is feasible to calculate internal dose for the period of atmospheric testing. Furthermore, later testing eras are still being evaluated as part of the NTS SEC petition review. Participation in these events could have led to significant internal exposures for some LLNL workers and should be thoroughly considered in the LLNL TBD.

No site profiles currently exist for many of the Plowshare events (i.e., Amchitka, Alaska, Hattiesburg, Mississippi, Farmington, New Mexico, Central Nevada, Rifle, Colorado, or the PPG) to provide guidance on how to assess potential measured and missed dose during the course of these tests. This facet of exposure to LLNL employees requires treatment in the site profile or a TIB to inform the dose reconstruction process.

In addition to weapons testing, LLNL participated in other programs at NTS. LLNL was involved in the development and operation of the Super-Kukla and Fran reactors at NTS. In the case of Super-Kukla, neutron activation of structural components occurred as a result of the prompt burst:

> *Surveys and sampling were conducted at the Super-Kukla reactor to determine why post-burst gamma measurements were elevated. Studies indicated that there was neutron activation of the structural components in the containment building (Johnson 1965).*

LLNL participated in what was referred to as Project Pluto at Jackass Flats at the NTS beginning in 1957. The project objective was to study nuclear ramjet propulsion for the Air Force. Several experiments were conducted to explore the use of atomic energy to propel rockets. Two research reactors (Tory-IIA and Tory-IIC) were built and tested as a part of this program. Subcritical

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shots were conducted at NTS, including shots during the test moratorium from 1959–1961. The test devices had all the elements of a full-scale nuclear test, but not enough fissile material to go critical. These tests were typically underground tests, although some subcritical shots were conducted above ground, such as the Vortex Project. A more complete analysis of LLNL activities at the test site is needed to investigate the potential internal and external exposures, particularly missed dose situations.

In summary, the evaluation of dose from LLNL personnel participation in weapons testing, subcritical experiments, and safety shots are not adequately considered in the TBD. There is no information on how internal and neutron dose reconstruction issues, previously identified at the testing sites during atmospheric testing, will be overcome. No consideration was given to follow-up decontamination activities after the end of testing in the Pacific. LLNL's participation in these events should be evaluated to determine if it was feasible to calculate dose while present at test sites. In addition, where dose reconstruction is feasible, a missed-dose methodology should be included for unmonitored or inadequately monitored workers who participated in activities at PPG, NTS, and other offsite areas.

OTIB-0033 Rev.00, *Application of Internal Doses Based on Claimant-favorable Assumptions for Processing Best Estimates* (ORAUT 2005c), in Attachment A, "Exposure Potentials," lists examples of work locations that NIOSH identifies as having high potential for airborne activity (alpha, beta/gamma, and/or uranium). This includes LLNL-sponsored weapons testing sites and weapons research and development (R&D) facilities.

5.2 INADEQUATE CONSIDERATION HAS BEEN GIVEN IN THE SITE PROFILE TO POTENTIAL EXPOSURE RECEIVED AT SITE 300

The site profile is incomplete in its description of activities occurring at Site 300 and the potential radiological exposure conditions associated with this area of LLNL. The Site Description TBD, in Table 2-2, "Site Activities by Building and Associated Radionuclides," indicates that the radioactive hazards associated with Site 300 include explosive testing, linear accelerators, DU, accelerator activation products (i.e., N-13, Ar-41, and O-15), and tritium (Maisler, 2005b, pg. 13).

> *For Site 300, radionuclides of significance were selected according to the inventory of radioactive materials and the type of work performed at the site. Specifically, the presence of depleted uranium (DU) indicated the analysis of U-238 and U-235. For the purpose of this TBD, the dose reconstructor should assign the dose associated with U-235 and U-234 for depleted uranium. For the periods of 1961 through 1971, the gross alpha concentration for Site 300 should be used to calculate the presence of U-235 and a second calculation using U-234; the assigned dose should be selected from the higher of the two calculations. The gross beta concentration should be assumed to be thorium-234.* (Thomas 2005, pg. 11)

The TBD has little discussion on fabrication, pressing, and machine shops located in the area, and the waste management and D&D activities have been overlooked.

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Site 300 was established in 1955 to support weapons R&D. Tests at Site 300 included weapons and explosives detonations, recovery of blast data, destructive and nondestructive materials testing, fabricating explosive components, developing high-energy explosives, radiography, particle beam studies, and waste disposal and treatment. Testing of weapons was done on firing tables on open concrete or gravel pads (Strauss 2004). Wagner and Diaconoff (1974) describe Site 300 activities below:

> *Hydrodynamics experiments using high explosives are an integral and essential part of the development of nuclear explosive technology, as well as other areas of research at LLL. The bulk of this work at the Laboratory is done at the firing bunkers at Site 300. These bunkers were built and instrumented between 1957 and 1967….*
>
> *There are five major firing bunkers at Site 300. The types of experimental configurations range from simple explosive-drive plates for fundamental hydrodynamics research to complete nuclear device assemblies (without fissile material, of course).*

Hydrodynamic experiments were done on firing tables on open concrete or gravel pads (Strauss 2004). Prior to the bunkers being developed, it is uncertain what protective measures were in place. The number of hydrodynamic experiments decreased over time, with the preponderance of the experiments conducted in the earlier years.

> *The hydrodiagnostics techniques used at the bunkers include flash radiography, high speed streaking and framing cameras, fast optical and electrical pins and neutron detection equipment. The trend over the past several years has been toward increasing use of several of these types of diagnostics on each experiment, and toward more accurate and sophisticated measurements of each type. This has resulted in significant economies. For example, nearly two hundred hydro experiments were required for the development of the W-45 in the late 1950s, whereas the W-75, if completed, would have needed less than one-tenth that number. During the mid-1960s, most nuclear experiments required about ten hydro experiments during their design; now even radically new designs may require only two or three.* (Wagner and Diaconoff 1974)

Site 300 was added to the Environmental Protection Agency (EPA) National Priority List (NPL) on August 30, 1990, because of contaminants (both radiological and chemical) found in the LLNL groundwater and the total tonnage of material deposited in Site 300 landfills. Site 300 historically operated dry wells, waste-water lagoons, and solid waste landfills. Solid waste landfills accepted waste from the LLNL main site, Site 300, and LBNL (EPA 1990). Radionuclide contaminants found in the soil and/or groundwater includes primarily tritium and DU.

The Occupational Internal Dose TBD indicates that tritium and DU are the radionuclides of concern (Berger and Szalinski 2005, pp. 13–14). In Table 5-4 of the TBD, the frequency of uranium bioassay and in-vivo counts are listed as semiannually and annually, respectively,

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starting in 1985 (Berger and Szalinski 2005, pp. 13–14, 16). The earliest uranium bioassays found in the MAPPER database are from 1958. It is uncertain for what areas the gross alpha bioassay was collected in the database. Site experts have indicated little or no bioassay was requested for workers involved in early hydrotests, and this seems to be supported by the lack of bioassay data in their files. The initial radionuclides involved in hydroshots were not limited to DU and tritium, as is indicated in a memorandum from R.E. Batzel to J.A. Perkins (Batzel 1976a):

> *LLL is proposing an extension of the Site 300 operation procedure to enable conducting experiments that do not increase hazards to the public, but are not technically within present guidelines. Since 1955 the Laboratory has used Site 300 for testing and diagnostics work with high explosives. Under the current guidelines the following radioactive and toxic materials are the only ones which may be released to the atmosphere during experiments: natural uranium, depleted uranium, natural thorium, tritium and beryllium.*

Sewell (1959) authorized the thorium hydrodynamics program at Site 300, provided that several safety requirements were met. Other radionuclides used in testing included Po-210 and U-235 (Batzel 1976b). No thorium- or Po-210-specific bioassay data are available prior to 1968 and 1971, respectively. The available bioassay data are limited and may not have included Site 300 workers. It is not clear from the MAPPER database whether gross alpha bioassay were collected from these individuals, since personal identifiers are not available. Further evaluation of the implemented monitoring for this area and its adequacy for the radionuclides involved in tests is necessary. This analysis should include waste handling and D&D workers, as well as those present from the Main Site for hydroshots.

Consideration should be given to the potential extremity exposures from hand contact with thorium and uranium:

> *Hand contact with thorium or thorium alloy shall be limited to ten working hours per week (Sewell 1959).*

As previously mentioned, Site 300 at LLNL was placed on the NPL in 1990. Environmental contamination was characterized as chemical, radioactive, and mixed. Groundwater and soil were contaminated with a number of toxic chemicals, as well as tritium and U-238 (EPA 1990). It is uncertain whether thorium and its daughters and enriched uranium were evaluated, since this information related to thorium and enriched uranium was integrated with classified records. Environmental internal dose is assigned based on the following technique (Thomas 2005, pg. 14).

> *For Site 300, radionuclides of significance were selected according to the inventory of radioactive materials and the type of work performed at that site. Specifically, the presence of depleted uranium (DU) indicated the analysis of ^{238}U and ^{235}U. For the purpose of this TBD, the dose reconstructor should assign the dose associated with ^{235}U and ^{234}U for depleted uranium. For periods of 1961 through 1971, the gross alpha concentration for Site 300 should be used to*

calculate the presence of ^{235}U and a second calculation using 234U; the assigned dose should be selected from the higher of the two calculations. The gross beta concentration should be assumed to be thorium 234.

The Environmental Dose TBD provides maximum annual median intakes for gross alpha and gross beta from 1961–1971. After 1971, maximum annual median intakes are provided for U-235, U-238, and Pu-239/240 (Thomas 2005, pg. 14). The TBD provides no method for the assignment of environmental dose for uranium and plutonium prior to 1961 and for tritium prior to 1972. In addition, no consideration was given to the contamination of soil and groundwater at the dry wells, waste water lagoons, and solid waste landfills.

In summary, minimal dose reconstruction guidance for Site 300 is provided for internal and environmental occupational dose. Internal dosimetry models assume tritium and DU were the radionuclides of concern. Thorium and daughters, enriched uranium and daughters, and Po-210 have not been treated in the TBD as potential internal exposure hazards. A method for the determination of missed dose from these radionuclides and other radionuclides encountered in waste areas at Site 300 is needed. In addition, a method for assignment of environmental dose for uranium and plutonium prior to 1961 and tritium prior to 1972 from waste handling and D&D is needed.

5.3 COMPLETENESS AND ACCURACY OF THE DATA USED IN DOSE RECONSTRUCTION IS LACKING IN THE INTERNAL DOSE TBD

Information available for dose reconstruction, especially for those involved in testing and special projects, is limited, inadequate, or in some cases, not available. NIOSH briefly discusses the quality of the bioassay data and notes that it is acceptable; however, there is no discussion in the Occupational Internal Dose TBD (Berger and Szalinski 2005) regarding what means of verification were used to establish the completeness and consistency of data provided to NIOSH. There are major issues with verifying the accuracy and usefulness of the data in MAPPER. LLNL staff members have indicated some bioassay cannot be confidently associated with a specific person; there are ambiguities in some analytes reported; large negative results are included for later periods; and letters in the sample type column do not always indicate whether the sample was urine or fecal and sample volume and mass must be interpreted carefully. There is very little discussion in the TBD about the quality of the early data (1950s–1960s). With the inconsistencies in MAPPER, the use of these data for a coworker model is suspect. The existence of bioassay results with classified datasets leads to questions regarding the adequacy of information being provided in the claimant files.

There are major issues with verifying the accuracy and usefulness of the data in the bioassay database (i.e., "MAPPER," although not identified by this name in the TBD). These data may need a review by radiochemists and internal dosimetrists prior to use to ensure validity. If this is the major database storing bioassay data for the site or is derived from the same source that is being used to generate information for claimants' files, then there is a significant probability that information in the files may be inadequate.

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Section 5.1 of the Occupational Internal Dose TBD (Berger and Szalinski 2005) states the following:

> *A review of in-house procedures used to assess the concentration of radioactivity in urine indicates that quality control steps were an integral part of the process (LLNL 1979). For example, LLNL ran duplicates consistently, and comparisons of results to "known quantities" were a critical step. Therefore, in vitro results from in-house processing are generally reliable. However, interpretation of those results can be difficult, primarily because they might not have considered the contribution of environmental radioactivity (i.e., uranium, thorium)…*

There is very little discussion in the TBD about the quality of the earlier data (1950s–1960s), and it is possible that these data were reported without any uncertainty (error) value, which would provide information on the precision of the analysis and possibly actual detection levels. A review of the bioassay analysis procedures for all of the "eras" of analytical work should be considered to determine the level of confidence that can be placed in the results that will be used for dose and intake analysis.

The statement that uranium and thorium could cause difficulty with interpretations is correct for analysis of gross alpha, gross beta, and naturally occurring uranium and thorium isotopes in bioassay samples. The statement in the TBD (Berger and Szalinski 2005) that "they might not have considered the contribution of environmental radioactivity…" is not an important issue with the analysis of the samples. This is a bioassay interpretation issue, because the laboratory only reports the total quantity or concentration of the radionuclides detected in a sample.

The MAPPER database was also reviewed, and there are several gross alpha and gross beta bioassay results in the database up through 1996. This is into a period that isotopic radionuclide analysis was available and typically performed for plutonium, along with specific elemental analysis of uranium. There is no discussion of what radionuclides to assume for association with these gross alpha and gross beta results in the more recent years, or whether or not these are even useful for an employee who was being monitored using isotopic and/or elemental analysis. The database shows "MFP" for the radionuclide in several results from the 1960s to 1980s. It can be assumed that this means mixed fission products, as it does in the TBD. The TBD does not address which radionuclides should be assumed to be in any intake determined from MFP sample results (e.g., Cs-137, Sr-90, I-131, etc.). NIOSH has developed guidance for interpreting gross beta bioassay, OTIB-0054 (ORAUT 2007f); however, this TIB only applies to reactor operations, reactor fuel examination and dissolution, and high-level waste management, which are not representative of all the sources the bioassay was used to monitor (e.g., core sample processing).

The MAPPER database was provided with a letter from the LLNL Radiation Safety Section (Mansfield 2006) warning about the accuracy problems with the database. Listed below is a summary of the problems that have been identified with the database:

- There are some bioassay data that cannot be confidently associated with a specific person.

- The actual day of the month that a sample was taken was unknown for some bioassays. These were assigned to the first day of the month arbitrarily.

- There was occasional ambiguity with the actual analytes reported in the results; for example, U28 and U38 were assumed to be U-238.

- There was a period of large negative results (e.g., Pu-239 of –6.976 dpm) in late 1996 that are called a "sort of artifact."

- There are some typographical errors left uncorrected in the unit's column.

- There are some letters other than the typical U (urine) or F (fecal) in the media column, such as B, R, and S. R and S are likely to be "Rush" or "Special" entries that were incorrectly put in this column rather than the Priority column. If the actual sample media was left out of the entry, then a claimant-favorable assumption will need to be made as to the sample being urine or fecal. Another sample result was determined to be a nose and throat swab result, instead of the urine sample indication it was given with a U.

- Assumptions about sample volume or mass must be made carefully, especially for plutonium urine samples, which during the later years (starting in the 1980s), were split into two approximately equal volumes when analyzed for both plutonium and gross alpha. In these cases, the result for a full sample would require doubling the reported result.

In summary, the letter warns NIOSH to use this database only in a critical manner, due to the problems discussed above. NIOSH should identify screening methods for dose reconstructors that will enable them to determine when data is usable. If NIOSH does not screen this data adequately, data interpretation could be done inaccurately and dose could be underestimated. Examples of inaccurate interpretation are as follows:

- An inaccurate sample date assumption could lead to underestimating the dose if the date chosen is too close in time to the assumed or known intake date.

- Not knowing that a sample was split into two equal volumes and analyzed for both plutonium and gross alpha could lead to underestimating the dose by as much as 50%.

In its response to SC&A's internal dose section question #1 (Attachment 3), NIOSH states that the database is used only for the coworker study and not for individual claims, which use hard copy records provided by the site. They are aware of the specific problems with the database, and have discussed interpretation of the data with site personnel. However, this acknowledgement and corresponding guidance to dose reconstructors needs to be included in the TBD.

Finally, it is notable that during site expert interviews with former workers, concerns were raised to SC&A regarding the completeness and accuracy of historic LLNL radiation exposure records.

The hierarchy of data used in the dose reconstruction process begins with the use of individual monitoring data as a priority. This is fundamental to the performance of dose reconstruction.

5.4 INADEQUATE CONSIDERATION HAS BEEN GIVEN IN THE TBD TO POTENTIAL EXPOSURE AND MISSED DOSE FROM SECONDARY RADIONUCLIDES

Numerous "secondary" radionuclides have been handled at LLNL in varying quantities. According to Occupational Internal Dose TBD (Berger and Szalinski 2005), these have included radium, Th-228, Th-232, Am-241, U-233, Cm-244, C-252, Pu-238, C-14, Na-22, P-32, S-35, I-125, I-131, Sr-90, N-13, and O-15, along with other fission products and activation products. A lot of bioassay data in the database are identified as gross alpha and gross beta results, and NIOSH has not identified which, if any, of these secondary radionuclides may be associated with these data. NIOSH has developed guidance for interpreting gross beta bioassay, OTIB-0054 (ORAUT 2007f); however, this only applies to reactor operations, reactor fuel examination and dissolution, and high-level waste management, which are not representative of all the sources for which the bioassay was used to monitor (e.g., core sample processing). NIOSH has commented that the next revision to the Occupational Internal Dose TBD will contain guidance on interpretation of gross alpha, gross beta, and fission product bioassay results.

Radium is not identified as being used in any buildings or projects to a great extent; however, there is evidence that it must be at the site in some abundance. One of the few incidents that are mentioned in the TBD involved radium (Leahy 1975). In Attachment A of the Occupational Internal Dose TBD (Berger and Szalinski 2005), Building 253 has Ra-226 at 0.015, Po-218 at 0.33, Pb-214 at 0.33, and Bi-214 at 0.33 of the Activity Fraction for the building, which means that Ra-226 and the principal radon progeny add up to all of the radioactivity in the building. If these are not from natural radium and radon sources in the building materials, then an accounting of the dose from these radionuclides should be included in a worker's dose. At the Building 514 Tank Farm, Ra-226 is 1.55E-4 and Th-228 is 6.023E-3 of the activity in the total, which puts these two radionuclides in the top 20 of the 80 radionuclides listed for this building, which is a waste facility and likely received its radionuclides from buildings throughout the site. This is another indicator that there may have been some substantial exposure to radon and thoron at the site. During the site interviews, employees stated that Th-232 was handled heavily during the earlier years of weapons testing, and according to Table 5-5 "Bioassay Detection Levels," there were no bioassays specific for thorium prior to 1970. Upon further questioning about the handling of internal doses from thorium exposure, NIOSH stated that further guidance will be given in the revision of the TBD, with the focus on use of gross-alpha urinalysis and WBC data for the post-1970 years. NIOSH also noted that an "83.14 SEC has been proposed for the early years at LLNL (through 1973)." (See Attachment 3 for these responses.)

It is illustrative that Sr-90 use in projects is not discussed and this makes up 20.5 % of the activity in the Building 514 Tank Farm. This indicates a potentially large source of Sr-90 at the site that needs discussion in the bioassay interpretation guidance. There is no specific discussion about intakes that could have occurred at the accelerator buildings, which could have significant levels of activated gases (N-13, O-15, etc.), yet there is a reference (Ozaki 1980) in the reference

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list that may be applicable. This infers that these could be significant and should be identified in the text of the TBD.

In its response to SC&A's internal dose section question #2 (see Attachment 3), NIOSH indicates that the list of "alpha emitters is small enough to limit the choices and determine a default" for gross alpha bioassay results. This may be a reasonable statement, but it will be important for NIOSH to give guidance that directs the dose reconstructor to use a claimant-favorable assumption for the alpha emitter(s) identified in intakes with gross alpha data. NIOSH does identify that "gross beta results are more problematic and a solution is still being discussed," which indicates a very careful approach is needed to identify all applicable radionuclides that could have been detected with this bioassay, so that claimant-favorable assumptions are made. In its response to question #17 (Attachment 3) regarding possible significant sources of Ra-226 and Ra-228, NIOSH identifies that it has not yet addressed the determination whether there were any projects that could have used these and caused significant radon and/or thoron exposures, but they indicate it will be reviewed.

5.5 THE TBD PROVIDES NO GUIDANCE ON BIOASSAY DATA FOR INTAKES OF TRITIUM, METAL TRITIDES, OR ORGANICALLY BOUND TRITIUM

Tritium in metal hydrides are special chemical forms for tritium, also called metal tritides (MTs). These MTs are somewhat insoluble forms of tritium compounds (Inkret et al. 1999, Cheng et al. 1997) that do not exhibit similar biokinetic behavior to the more common forms of tritium, such as tritiated water (HTO) or elemental tritium. Tritium from MTs does not enter the systemic compartment as quickly as HTO after inhalation and, therefore, the interpretation of tritium urine bioassay data cannot be treated with standard tritium excretion models (McConville and Woods 1995). Due to being relatively insoluble, inhaled MTs deliver the highest component of dose contribution to the lungs. Tritium from these particles also can convert to organically bound tritium forms (OBTs) from contact with lung tissue and further complicate the metabolic process (DOE 2004).

Organically bound tritium forms (OBTs) were not discussed in the site profile TBD. There is limited guidance on the interpretation of bioassay data for intakes of tritium, MTs, or OTB. However, general guidance has recently been provided in OTIB-0066 (ORAUT 2007g), which was issued while this SC&A review was underway. OTIB-0066 addresses the calculation of dose from intakes of special tritium compounds, but only partially addresses some of the issues discussed below).

Not specifically addressing MTs or OBTs in terms of historic applications at LLNL could lead to underestimating doses. According to the Site Description TBD, ORAUT-TKBS-0035-2 (Maisler 2005b), Building 331 (Hydrogen/Tritium Research Facility) had the bulk of the tritium inventory in elemental form or metal hydrides. Tritium gas and salts were handled as a part of the weapons program and the fusion program. The exact forms of tritium encountered by facility are not available; however, over the course of operations, LLNL has handled tritides in the form of lithium tritide (LiT), lithium deuterium tritide (LiDT), titanium tritide, and uranium tritide. Organically bound tritium, such as tritiated pump oil, rust, pump oil droplets, tritiated methane, and tritiated solvents, were formed during operations with HTO and tritium gas (HT). A majority of the tritium handled was in the form of HT. Tritiated water (HTO) was produced by exposure of HT and some special tritium compounds to air. Tritium-handling operations, R&D activities, and D&D activities have exposed workers to other forms of tritium.

The dose consequences from special tritium compounds may be significantly larger than those from HTO; therefore, NIOSH needs to be familiar with the special tritium compounds handled, the quantities of material, the locations and time periods of potential exposure, and the physical behaviors of tritium compounds in the environment (e.g., conversion to HTO, formation of rust) to correctly characterize tritium exposure. Bounding techniques proposed in ORAUT-OTIB-0066, *Calculation of Dose from Special Tritium Compounds* (ORAUT 2007g), cannot be effectively developed and applied without some basic understanding of the compounds handled and the extent to which individuals were exposed. In the recommendations from ORAUT-OTIB-0066, it states that, "the selection of the appropriate tritium compound in an intake evaluation must usually be based on process knowledge of the source terms in the workplace." It is important that the dose reconstructor chooses claimant-favorable forms of tritium for the dose estimation if there is a lack of process knowledge about the form that may have been involved with exposures. The dose to the lung from intakes of MTs can be underestimated by orders of magnitude if it is incorrectly assumed that the dose can be calculated with the methods used for HTO (ORAUT 2007g).

The main types of OBTs found are tritiated solvents, tritiated oil, and solid particulates (e.g., organic dust, plastics, etc.). The dose from intakes of OBTs can be different than HTO intakes of the same activity and is dependent on the specific chemical compound in which the material is bound. The effective dose equivalent (EDE) per unit uptake has been estimated to be two times larger for OBT than HTO (DOE 2004). OBTs in the form of solid particulates reside in the lungs for a longer period of time, resulting in higher dose to the lungs. ORAUT-OTIB-0066, *Calculation of Dose from Special Tritium Compounds* (ORAUT 2007g), states that, "a Type 1 calculation underestimates systemic dose approximately 30% for intakes of OBT because half of the intake is not uniformly distributed in the body-water space." In the recommendations from ORAUT-OTIB-0066, it states that this method [from ORAUT-OTIB-0011 (ORAUT 2004b)] can be used without modification to calculate doses from intakes of OBTs to all organs and tissues, which appears to be non-favorable for claimants if it underestimates systemic dose by approximately 30%. More information on how prevalent OBTs are in the LLNL work environments should be gathered, and consideration given to the potential difference in resulting dose.

Special tritium compounds are not explicitly discussed in the Occupational Internal Dose TBD. Dose reconstructors should be made aware of the characteristics of special tritium compounds (STCs) excretion in urine to enable them to distinguish between STCs and tritium oxide or HT. For example, McConville and Woods (1995) demonstrated, with individual excretion data following tritide uptakes, that tritium excretion curves for particulate tritides do not follow a simple exponential curve, as is the case with HTO. In the case of these individuals, tritides built up for a few days followed by a more traditional elimination curve. In 1976, a worker in the Tritium Facility at LLNL had a substantial tritium exposure and the urine samples collected over several days did not show the expected decrease in tritium concentration, indicating that there probably have been significant intakes of special tritium compounds (Dupzyk et al. 1978).

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In order to develop a bounding exposure, NIOSH would need to make themselves familiar with the special tritium compounds handled, the quantities of material, and the locations and time periods of potential exposure. Some thought should be given to the chemical behavior of tritium, especially as it related to the D&D of aging tritium facilities and other facilities where tritium was a byproduct of operations.

The Internal Dose TBD does not discuss how to differentiate between intakes of HTO, elemental forms, OBTs, or MTs, and does not discuss tritium dosimetry to any significant extent, even though this is one of the major radionuclides used at the site.

In its response to SC&A's internal dose section question #5 (see Attachment 3), NIOSH stated that, "It is not known if metal tritides were handled at LLNL…" As noted above, the Site Description TBD identifies that the main hydrogen/tritium research facility (Building 331) had the bulk of the tritium in metal hydrides or elemental forms. Tritium in metal hydride is also a metal tritide; therefore, it is known that these were handled, and as noted, probably in large fractions of the total source term for this building. In response to further questioning, NIOSH has stated that, "metal tritides and organically bound tritium were used at LLNL, but in very small quantities compared to tritium gas (HT)." If this is the case, then NIOSH needs to provide substantiation, as most of the stored tritium has been in the form of MTs and there was likelihood of various oils and solvents getting contaminated with tritium, creating OBTs. NIOSH should investigate further to determine if the probability of MTs and OBTs being involved in intake incidents may have been higher than the other typical forms (HT and HTO).

NIOSH also responded that, "*In general, tritium tritide contributes little dose unless there are large quantities of contamination found in the work place*." As noted above, an inhalation intake of MTs delivers the highest component of dose to the lungs, because it does not get uniformly distributed throughout the body quickly like HTO. Instead, it sits in the lungs absorbing into the blood system at rates that can be very slow, depending on the metal compound. Therefore, for a claimant with a lung cancer, assuming a metal tritide intake of low solubility (slow absorption rate) when there is no evidence to rule it out, is most likely claimant favorable. Another issue with this statement is that it appears NIOSH has not performed an investigation into the contamination levels found in the workplace, since this is not discussed in any of the TBDs, and therefore cannot make general assumptions that large quantities of contamination could not have existed.

In summary, NIOSH has acknowledged that MTs and OBTs must be treated differently for tritium dose assessments in the development of their guidance document, OTIB-0066, (ORAUT 2007g). However, due to the lack of description in the TBD regarding the exposure potential to these compounds, a concern remains about how NIOSH will identify when they are to be assumed in dose assessments.

5.6 THE TBD DOES NOT IDENTIFY POSSIBLE CHEMICAL FORMS OF AIRBORNE RADONUCLIDES TO WHICH WORKERS HAVE BEEN EXPOSED

The Internal Dose TBD does not identify the possible chemical forms of the airborne radionuclides that workers could have been exposed to, which will give guidance on the solubility (absorption) class to use (F, M, or S) for inhalation and intake dose assessment. The TBD states "Other variables such as particle sizes and clearance classes can be readily reconstructed from historical records." No specific references are made to these historical records. There is no discussion on the potential for exposures to very insoluble and slowly absorbed high-fired plutonium.

LLNL undoubtedly worked with many radionuclides that could have been in various chemical forms that may have exposed workers to intakes. The lack of identification of the chemical forms of the radionuclides leaves out guidance to the dose reconstructor on which solubility classes to assume when interpreting bioassay to determine the intake quantity (ICRP 1997). The correct solubility class is also needed when calculating the dose to specific organs from intakes (ICRP 1994). These relationships between chemical form/solubility class, intake determination from bioassay, and dose to organs per intake amount are dynamic.

Inhalation and ingestion intakes of insoluble forms of radionuclides (e.g., PuO_2, plutonium dioxide, which is class S) are typically not detected by urine bioassay with as much sensitivity as intakes of more soluble forms (e.g., $PuNO_3$, plutonium nitrate, which is class M). This is due to the very low absorption of the insoluble forms into the systemic compartment. Therefore, insoluble form radionuclide intakes can be many times larger than soluble form radionuclide intakes when interpreting the same urine bioassay data. Highly soluble forms of radionuclides can move through the body and be excreted before detection if the sampling frequency is not high enough to detect significant intakes before these become undetectable. Inhalation intakes of insoluble forms of radionuclides are often detected by in-vivo counts with more sensitivity than soluble forms of the same particle size, because the insoluble forms will remain in the lungs for a much longer time, giving a stronger source for the in-vivo system to detect. Ingestion intakes of soluble forms of radionuclides are detected with more sensitivity in urine bioassay than insoluble forms of the radionuclides, because a larger fraction of the radionuclides in soluble forms are absorbed through the gut into the systemic compartment. For insoluble radionuclides, a larger fraction of the activity passes through the digestive tract and is excreted in the feces. Fecal bioassay is the most sensitive bioassay for detecting inhalation or ingestion of insoluble forms of radionuclides, and it is important to determine if fecal bioassay data are special bioassay taken after an incident or part of a routine bioassay monitoring program, in order to apply bioassay modeling appropriately.

Inhaled insoluble forms of radionuclides give much higher doses per unit intake to regions of the lungs, due to the long clearance half-lives from this organ compared to more soluble forms. Inhaled and ingested soluble forms of radionuclides can give much higher doses to all organs (other than the lungs for inhalation exposures), due to the higher fraction of radionuclides being absorbed into the systemic compartment and distributed to organs at a higher rate. Therefore, the chemical form (which determines solubility) of radionuclides has a major impact on the eventual determination of intake quantities and internal doses to organs, and assumptions for these chemical forms should be claimant favorable when there are different possible forms involved with exposures. To illustrate, based on ICRP Publication 68 (ICRP 1994), the dose to the lungs from Pu-239 can more than double per amount inhaled when assuming an insoluble oxide (class S) form instead of more soluble forms, such as plutonium nitrate. In another example, the

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dose to the lungs from uranium is approximately 100 times larger per amount inhaled when assuming a highly insoluble form instead of a highly soluble form, such as uranium hexafluoride.

In its response to SC&A's internal dose section question #8 (see Attachment 3), NIOSH indicated that the information on chemical forms of radionuclides and solubility classes is not available at this time. It also states that claimant-favorable assumptions would most likely be used for the majority of cases, even if there was building-specific information. This approach of not identifying chemical forms and/or solubility information appears to be a departure from the approach in writing internal dose TBDs, as provided (for example) in Argall 2004, Millard 2004, Bollenbacher et al. 2006, and Berger 2004, and specific references to the procedures that internal dose reconstructors should use to choose appropriate solubility classes is needed if this information is not going to be provided.

5.7 THE INTERNAL DOSE TBD HAS NOT ADEQUATELY IDENTIFIED AND REVIEWED APPLICABLE BIOASSAY FREQUENCIES AND DETECTION LEVELS

In many cases, the information given for bioassay frequencies and detection levels are not useful, because of inaccuracy or lack of information. Doses may not be calculated accurately and may not be claimant-favorable without this information. Table 5-4, entitled "In-vivo and In-vitro Sampling Frequencies" (Berger and Szalinski 2005), reveals items of concern about the understanding that NIOSH has for bioassay history at the site. In Table 5-4, there are 15 in-vitro urine bioassay types (all for a period of an unknown beginning date through 1966) that list "Not Specified" in the Radionuclide identification column. In the period 2000–present, there is a whole-body (WB) in-vivo analysis listed with no radionuclides identified for the analysis (the entry in the Radionuclide column is blank). Therefore, there is no information provided on which radionuclides these bioassay frequencies apply to during these periods. There is no frequency or building shown for the in-vivo WB scans done from 1964–present for MFP radionuclides. This serves no purpose in assisting the dose reconstructor, other than to inform them that WB scans for MFPs were conducted at some time for some building(s) between now and 1964. Table 5-4 also shows little information on the bioassay frequencies for the earlier years (pre-1970s), which could be important for interpreting bioassay data to determine intakes. The frequencies for P-32 and C-14 are identified by "as applicable" and for I-131 "coordinated with work schedule" without any further explanation. Identifying the correct bioassay frequency can be important to the dose reconstructor for determining appropriate intake dates to assume and in the review of a bioassay history to help understand the claimant's potential exposures.

Table 5-5, entitled "Bioassay Detection Levels" (Berger and Szalinski 2005), has a few items that bring up concern about the ability of NIOSH to determine when bioassay results indicate intakes of radionculides (i.e., positive bioassay). First, it should be noted that a substantial amount of the detection levels listed are taken from references that were not developed at the site and may not be representative of the actual detection levels. The TBD states these were based on the LANL site experience and ICRP Publication 54 (ICRP 1989). There is no detection level for plutonium in urine (in-vitro bioassay) from 1988–1999. The minimum detectable activity (MDA) for Pu-239, 238 from 1967–1987, is stated as 0.03 pCi/24-h sample; however, it is identified as 0.051 dpm/sample (0.023 pCi/sample) in a 1979 document, *Radiochemical*

Procedures for Bioassay (Dupzyk 1979). In Table 5-5, the minimum detectable concentration (MDC), the quantity of radioactive material per volume, shown for uranium from 1978–1982 was 1 microgram/liter, but the 1979 document (Dupzyk 1979) shows that it is 0.1 microgram/liter. The 1979 document (Dupzyk 1979) also shows a radiochemical method for analyzing curium; however, Table 5-5 only identifies an MDA for samples analyzed starting in 2000. The 1979 document shows a radiochemical analysis for gross alpha that applies to plutonium, thorium, americium, curium, actinium, and neptunium, but there is no gross alpha analysis listed in Table 5-5. This is of great importance because several alpha emitters other than plutonium, uranium, and americium were handled in the earlier years at the site (in particular thorium, curium, and neptunium), and Table 5-5 does not provide MDAs for these in the early years. This points out that more research needs to be done on understanding the applicability of gross alpha results to exposures from these radionuclides prior to applicable specific radiochemical isotopic analysis.

It appears that the in-vitro analysis for HTO (tritium in urine) from 1952–1958 was done by GM counting. The entry in the next row of the table identifies HTO analysis for 1958–1968 by internal GM counting. This would infer that the 1952–1958 analysis was done using a GM counter with a window, since it was not stated to be "internal" GM counting. If the 1952–1958 data was acquired using GM counters with windows, then this should be reviewed to make sure that this technique was valid, due to potential shielding of the weak beta emissions (18.6 keV maximum beta) by the windows along with potential self-shielding within the prepared sample which may cause non-detection. The in-vitro urine analysis MDA of "100 picocuries per liter" for gross beta from 1960–1999 is identified as being for the radionuclides I-125, I-131, and S-35. However, I-125 is not a beta-emitter and, therefore, it is questionable to interpret it with gross beta bioassay data. The first period entry for DU, Natural U by fluorophotometric shown in the table, needs to be edited, because it shows 1949–1976; however, the site began operation in 1952.

5.8 AN APPROACH FOR DETERMINING INTERNAL DOSE FOR UNMONITORED OR INADEQUATELY MONITORED WORKERS DOES NOT ADDRESS PLUTONIUM, TRITIUM, OR OTHER RADIONUCLIDES

Upon being questioned in the earlier phase of the review about the lack of guidance in the Occupational Internal Dose TBD (Berger and Szalinski 2005), NIOSH stated that a coworker study was in development for the years in which bioassay was performed, and will determine bounding estimates for intakes of long-lived, long-retained nuclides for individuals that were subsequently monitored in later years. ORAUT-OTIB-0065, *Internal Dosimetry Coworker Data for Lawrence Livermore National Laboratory* (ORAUT 2007e), was issued and was evaluated to determine if unmonitored or inadequately monitored workers will be addressed appropriately. The document addressed potential internal doses from uranium exposures; however, no approaches are given for determining the internal doses to workers that were unmonitored or inadequately monitored for plutonium, tritium, or other radionuclides. This includes those workers that were exposed to radionuclides prior to any bioassay monitoring (appears to be <1960) and those not monitored or inadequately monitored after applicable bioassay became available.

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The Occupational Internal Dose TBD (Berger and Szalinski 2005) states in Section 5.1 that this document provides the approach for assessing internal dose for employees with either missing or no monitoring information, and it also gives information on the start of internal exposure potential and bioassay programs:

> *This document provides a uniform and consistent approach to assessing occupational internal dose at the Lawrence Livermore National Laboratory (LLNL) for dose reconstructions for NIOSH in relation to the EEOICPA. It provides guidance to dose reconstructors on input parameters that are specific to LLNL employees, as well as the approach for employees with either missing or no monitoring information.*
>
> *LLNL workers handled a variety of radionuclides as part of their routine work. The key elements in the source term were plutonium and tritium, although others were used at various times and in various forms. For the purposes of dose reconstruction it can be assumed that internal source terms were introduced at LLNL's inception on September 2, 1952.*

The Occupational Internal Dose TBD (Berger and Szalinski 2005) pointed out the following:

> *Prior to the early 1960s, the only methodology that LLNL used to monitor employees for intakes of radionuclides at LLNL was urine bioassay, with the primary focus on excreted tritium. It is not clear when bioassay monitoring first began, but it continues to this day for plutonium, americium, uranium, mixed fission products, a variety of tracer radionuclides, iodine, and tritium …."*

The TBD has a Section 5.3 titled "Assessment of Intake for Unmonitored Claimants." This section states the following:

> *The in-vivo bioassay sampling program at LLNL was extensive, and there was clear direction to supervisors on individual employee participation in the program. However, there is evidence that participation was not always enforced. Therefore, a means of assessing intake for unmonitored claimants is necessary.*

The *Internal Dosimetry Coworker Data for Lawrence Livermore National Laboratory*, OTIB-0065 (ORAUT 2007e), gives direction on estimating doses from intakes of uranium, but provides limited guidance on assessing intakes for plutonium, tritium, and other radionuclides by unmonitored claimants [albeit, OTIB-0066 (ORAUT 2007g) does provide guidance on calculation of dose from intakes of special tritium compounds]. It should be noted again that the database used for this coworker procedure on uranium has been identified to have several quality-related concerns described in Finding 5.3 in detail (see discussion on MAPPER database). This may undermine the validity of the guidance provided in this document.

If it is determined that coworker bioassay data is not useful in determining the doses for unmonitored or inadequately monitored claimants, several approaches can be evaluated for applicability. Air monitoring data (area and personal breathing zone) can be used to estimate inhalation intakes of radionuclides and internal doses if it is available and applicable when bioassay is unavailable (CFR 2005). A statement in Section 5.1 of the Occupational Internal Dose TBD (Berger and Szalinski 2005) identifies the performance of air sampling:

> *Air monitoring in workplaces and in the breathing zones of employees has been a common surveillance method. However, LLNL apparently did not use the data acquired through that program, which are not readily associated with individual exposures, to prepare the dose of record for employees.*

In addition, Section 5.3 of the TBD states the following:

> *Bioassays were supplemented with workplace and/or personal breathing zone airborne monitoring (Mansfield 1989, p. 10)….*

If air-monitoring data are used, then a determination of how representative the data are of the exposure the employee had is needed, due to the likelihood that certain types of air monitoring in an area may not accurately represent a given exposure (NRC 1993). Other assumptions need to be evaluated, such as the solubility class of the radionuclide(s) inhaled (to use the correct dose coefficient), breathing rate of the employee, and use of appropriate respirator protection factors, if respiratory protection is worn during exposure periods. Reasonable, claimant-favorable choices of breathing rates (light work, heavy work, resting) should be made. Adjustments to intakes for respiratory protection should not be taken unless the dose reconstructor has confidence that respiratory protection usage was adequately documented, including the type of respirator used, to identify protection factors and adequacy of the respiratory protection program and its implementation.

Loose (removable) surface contamination data can be used to estimate air concentrations if reasonable claimant-favorable resuspension factors are applied to the data and the location of the survey data are applicable. If this approach is used, then the assumptions discussed above regarding solubility class, breathing rate, and respiratory protection will need to be addressed, since air concentration estimates would be used again for intake assessment. Surface contamination data can also be used to estimate ingestion intakes in areas that good personal contamination control practices may not have been followed.

Another approach may be to assume that intakes that could be or have been assessed to workers that had similar exposures and were monitored by bioassay are representative of intakes that unmonitored or inadequately monitored claimants may have had. This approach would require a determination of the accuracy of assuming that the unmonitored claimants were working in similar areas and performing similar tasks under similar radiological contamination and control conditions. If this approach is taken, then a determination should be made whether the average or maximum intakes assigned to monitored workers are the most reasonable claimant-favorable assumption, or if a statistical analysis of intakes assessed by bioassay is needed to estimate the intakes for these claimants favorably.

Several statements in the TBD point out that the supervisors were responsible for entering workers into available and appropriate bioassay programs, and one statement in the TBD

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indicates that participation in appropriate bioassay programs may not have been enforced in all cases. The dose reconstructor should determine if a worker did or did not participate in the appropriate bioassay program, and if the worker's supervisor(s) enforced the worker's participation in the appropriate bioassay program. An approach should be developed to determine how to account for doses from potential intakes that these workers may have had that went undetected. The approach should be described in detail in either this TBD, a TIB, or procedure that is available for review. The capability to identify whether a claimant was in any group of unmonitored or inadequately monitored employees will also be needed, which involves some method to determine the timeframes that these employees entered work locations with internal exposure potential during their work at LLNL.

In its response to SC&A's internal dose section question #3 (see Attachment 3), NIOSH indicated that at the time this question was posed, a coworker study was in development for the years in which bioassay was performed, and will determine bounding estimates for intakes of long-lived, long-retained nuclides for individuals that were subsequently monitored in later years. It also states that an approach is in development for unmonitored workers in the early years with no later monitoring or with potential for exposure to short-lived nuclides. Due to the concerns with the problems in the bioassay data in the database that NIOSH is using to perform this coworker data approach (i.e., the MAPPER database), it is recommended that NIOSH review historical radiological control program information (if available), such as surface and air contamination monitoring data, to assist in estimating intakes to these individuals, in particular for the unmonitored workers in the early years or with potential for exposure to the short-lived nuclides.

5.9 SPECIFIC GUIDANCE IS LACKING FOR INTAKE AND DOSE ASSESSMENT

There is a lack of specific guidance for intake and dose assessments, such as assumption of uranium enrichment for bioassay mass concentration interpretation, aging of weapons grade plutonium, use of in-vivo data, and use of air sampling data or other radiological control information to support intake assessment.

ORAUT-OTIB-0060, Internal Dose Reconstruction (ORAUT 2007c), provides guidance on many intake and parameter assumptions that should be made during dose assessments to maximize the dose that was potentially received by the claimant; however, the Occupational Internal Dose TBD (Berger and Szalinski 2005) still needs to provide some site-specific guidance to dose reconstructors. The assumption of uranium enrichment can change the dose by a fairly large factor when interpreting uranium mass concentration bioassay results, which are the results in which the bulk of uranium bioassay data is recorded. NIOSH responded to further questions that the assumed enrichment will be natural uranium in the next revision. The dose reconstructor needs to be aware of any possibility that highly enriched uranium intakes could have been monitored with bioassay uranium mass in the earlier days of lower sensitivity analysis (fluorophotometric), because the high specific activity from the U-234 component would give a rather large dose per unit detected and this would not be accounted for if natural uranium is the assumed enrichment. The TBD points out the different activity levels of the radionuclides in weapons grade plutonium over time for decay and ingrowth of Am-241; however, it does not give guidance on which age of plutonium to use or which is claimant favorable to use if more than one is possible. The TBD does not give any significant guidance on performing internal dosimetry for any exposures that could have occurred during activity at weapons testing sites. The TBD does not give any guidance on the use of breathing zone air sampling, which it states was done routinely, or in-vivo bioassay, which has been performed since the early 1960s for the support and refinement of intake and dose assessments.

In the response to question #7 of the internal dose section in Attachment 3, NIOSH states that, "A default value of 10 yr aged Pu is used in [dose reconstruction]." This guidance is not identified in the TBD, and if it is from another document, that document should be cited and referenced.

5.10 EXTERNAL DOSE RECORDS ARE INADEQUATELY CHARACTERIZED

LLNL is a large, complex site that has been in operation for over 50 years, with workers occupying several physical locations (LLNL proper, Site 300, PPG, and NTS). The Occupational External Dose TBD (Thomas and Szalinski 2007) states on page 7 that the personnel dosimetry records are generally available for all periods at LLNL for workers that had the potential for exposure to radiation. However, there may be some situations where dose records may not be adequate for some workers. This is especially true for early workers, before all the radiation hazards were identified and all workers were badged. Additionally, dosimetry may not have matched the exposure conditions at all the different work sites. Lack of, or inadequate, monitoring can lead to incorrect dose records and less than claimant-favorable dose reconstructions. These areas of concern are examined in more detail in the following sections.

5.10.1 1952–Present

5.10.1.1 Badging policies

Workers could have worked at different locations while employed at LLNL. These included the LLNL main area, Site 300, PPG, and NTS. It is not clear from the Occupational External Dose TBD (Thomas and Szalinski 2007) whether the badging polices were uniform at these different work locations for LLNL workers. It states on page 7 of the TBD (Thomas and Szalinski 2007) that workers could have worked at the NTS and other test areas, but does not provide any details on badging policies (i.e., did the LLNL workers take their badges with them to other sites, and if so, were the calibrations appropriate to the radiation fields present there?). If the workers obtained on-site badges when they worked at other test sites, were these doses recorded in the worker's records at LLNL, or does the dose reconstructor have to be aware of this and request DOE files from that site also? Many workers or their survivors may not recall all the trips to different sites. Additionally, were the LLNL or on-site badges calibrated for the type of exposures to which the LLNL workers were exposed?

5.10.1.2 Who was badged and when?

On page 15 of the TBD (Thomas and Szalinski 2007), it states that it was documented that all workers at Livermore were monitored for radiation beginning in 1954, but on page 9 it states that the policy of monitoring all workers began in May 1958. It is not clear from the TBD if the term "all workers entering the site were monitored since May 1958" (page 9) covers all workers, including prime and subcontract workers, D&D workers, rovers, private contractors, etc. This total badging policy is somewhat different than the criterion that is listed in Table 6-3 on page 14 of the TBD (Thomas and Szalinski 2007), where for 1952–present, it is stated that "All employees **with significant measurable exposure potential** were monitored continuously" [emphasis added]. This criterion would not necessarily include all workers entering the site. The latter statement is supported by gaps in monitoring, as noted on page 15 and annotation [7] of the TBD (Thomas and Szalinski 2007). It appears even for 1958–present, not all workers were monitored at any time; i.e., employees with low exposure potential were sometimes not monitored, such as some workers in administrative-type work from May 1958 onward.

5.10.1.3 Zero and blank entries

On page 9 of the TBD (Thomas and Szalinski 2007), it states that, "Doses below the detection limit were either recorded as zero or not recorded at all," and Table 6-5 on page 14 of the TBD states that, "(no data) [and] blanks should be interpreted as individual was monitored with zero results." If zeros are entered, it indicates that the worker was monitored for that period and the reading was between zero and MDL. However, a blank does not confirm that a worker was badged, or if a badge was read or recorded. A badge may not have been issued or it may have been lost or destroyed. This is especially important during 1952–1957, when not all workers were badged. Assigning a dose based on MDL for a blank entry does not insure that the potential dose received by a worker is correctly recorded.

5.10.2 1952–1957

5.10.2.1 Selection of workers for badging, 1952–1957

The Occupational External Dose TBD (Thomas and Szalinski 2007) uses the term "significant potential for exposure" to define who was badged during 1952–1957. However, this does not really provide sufficient information concerning who was badged during this period, i.e., what criteria established the technical basis for badging or not badging a worker. A more definite selection process is needed to ensure proper monitoring for dose reconstruction purposes. In addition, the validity of any coworker model derived from previously monitored workers' recorded doses depends on how the monitored population was selected (i.e., maximum exposed, randomly selected, and cohort badging data available for specific job locations).

5.10.2.2 Dose records, 1952–1957

Table 6-5 of the TBD (Thomas and Szalinski 2007, pg. 14) states that more than 95% of the employees were monitored before 1958. However, it does not state if this covers all workers, including prime and subcontract workers, temporary workers, rovers, private contractors, etc. Additionally, it is not stated if this 95% figure also applies to neutron monitoring; nor does it provide the breakdown of the percent monitored by year. This area needs further investigation and discussion in the TBD.

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5.10.2.3 Yearly badging results, 1952–1957

To determine if adequate badging was performed during 1952–1957 (when not all workers were monitored) and the applicability of this data to a coworker model, it is recommended that a table or tables be constructed with a breakdown of the monitoring data for beta/photons and neutrons, to include the following:

- Number of badge readings each year
- Total number of workers each year
- Percent of zeros each year
- Percent of blank entries each year
- Distribution of doses each year, including high, average/median, and low readings.
- Any dosimetry problem or adjustments for each year

Because of NIOSH's recent recommendation to use the n/p method to assign neutron dose instead of using the original NTA film readings, NTA dose of record will not be used (Thomas and Szalinski 2007). However, it is still important to determine the neutron badging policy and to analyze the NTA neutron monitoring results because, in many cases, the dose reconstructor will check to see if the worker was badged for neutrons using NTA film to decide if neutron dose assignment is warranted using the n/p method.

5.11 INADEQUACIES EXIST IN HOW DOSE OF RECORD IS COMPARED WITH WORKER'S ACTUAL DOSE; INSUFFICIENT BASIS PROVIDED FOR NEUTRON DOSE ESTIMATION

Throughout the Occupational External Dose TBD (Thomas and Szalinski 2007), the dose data records are presented as containing the correct dose received by the worker. However, a number of technical issues are not considered in this assumption. Lawrence Berkeley National Laboratory (LBNL) provided the dosimetry during 1952–1955. However, no details of calibration, response as a function of energy, geometry, or mixed fields, etc., were provided. This was still an era when film dosimetry was being developed and some problems existed in dosimetry. Additionally, these response functions were not covered after 1955, when LLNL provided the dosimetry. Nolan (1958) indicated that there had been some problems with the former film badge program, and that the new program was much better, but still could use some adjustments. (Also see Graham and Homann 1977 concerning TLD photon measurement errors.) These concerns apply to both beta/photon and the deviation and application of n/p values. It is stated on page 8 of the TBD (Thomas and Szalinski 2007) that the dose reconstructor can compare earlier dosimetry systems to current systems to evaluate their performance. However, this is an area that should be addressed in the TBD; it is arguable that the dose reconstructor should not be required to perform this task. Additionally, having each dose reconstructor perform this task could lead to inconsistency in dose reconstruction technique. The only adjustments to the photon doses mentioned in the TBD are an uncertainty factor of 1.3 for film and 1.2 for TLDs on page 16, and the recommendation of the use of exposure-to-organ DCFs prior to 1966, and Hp(10)-to-organ DCFs thereafter in Table 6-6 on page 15. The only adjustment to the neutron doses was the recommendation to multiply the recorded dose by a factor of 1.91 to account for the ICRP-60 weighting factors. This appears to be an oversimplification of dosimetry over a 50-year period. The areas that need to be addressed are presented in this section.

5.11.1 Photon dose

As dosimetry technology developed, response functions were refined and a better match was obtained between actual exposure and dose records. However, at most facilities, there were adjustments and uncertainties associated with dosimetry throughout the years. The Occupational External Dose TBD (Thomas and Szalinski 2007, pg. 14) makes the statement that no adjustments are recommended to the recorded photon doses. This would indicate that all photon dosimetry records at LLNL correctly represent the dose received by the workers during all periods and exposure conditions to all radiation sources within a small error, such as several percent. Most likely this was not the case, especially in the early years; for example, Kathren (1963) expressed concern about the measurement of doses from photons of <100 keV and of beta exposure. Uncertainty factors of 1.3 for film and 1.2 for TLDs, as recommended in the TBD (Thomas and Szalinski 2007), do not appear to be claimant favorable, in view of other DOE site TBDs, which use higher uncertainty factors. These other site TBDs list uncertainty factors of 1.3 or more at SRS (Scalsky 2005) and at LLNL (Hankins 1978a), where it is indicated that TLD albedo-neutron dosimeters could be used with an expected accuracy of ±25 to 33%. Additionally, it could not be found that the NIOSH's OCAS-IG-001 (NIOSH 2002) document supports using an uncertainty value of 1.2 in view of page 16 of that document, which states laboratory uncertainty alone is never less than 20%:

> *As noted by the National Research Council subcommittee, laboratory uncertainty was never less than 1.2. As long as a standard error estimate is greater than 10%, the 95% Uncertainty Factor K(E)) is also never less than 1.2.*

According to this, laboratory uncertainties (calibration, chemical processing, reading, etc.) alone are usually considered to be around 20%. In addition, radiological (energy spectra, body PA-AP-rotational positions, and other field variables) and environmental (moisture, light, temperature, chemical exposures, etc.) uncertainties must be considered. These combined uncertainties usually range around 30%–40% under actual working conditions, especially during the earlier years of film dosimetry, such as prior to 1971.

5.11.2 Neutron dose

In Rev. 01 of the Occupational External Dose TBD (Thomas and Szalinski 2007), page 13, it is recommended that the dose reconstructor should use the n/p ratio method to determine neutron doses to workers with the potential for neutron exposure during the period 1952–1969. It is assumed from the first part of the paragraph that this includes 1969, although in the middle of the paragraph it states, "…prior to 1969." The use of the n/p method eliminates a lot of uncertainties that have plagued the use of NTA neutron film throughout its history. However, at the same time, it puts an additional burden on the adequacy and accuracy of the measured/assigned photon dose. Using completely separate neutron (NTA) and photon (film) monitoring methods provided a checks-and-balances system, while at the same time, the accuracy of one measurement did not affect the accuracy of the other. Using only the photon dose to assign the total photon-plus-neutron dose requires more stringent control over the assigned photon dose, because an error or bias in the photon dose will not only be carried through in the final photon dose, but will be multiplied by the n/p factor and compounded by the dose to dose-equivalent conversion factors in assigning the final dose. Therefore, a number of details concerning neutron dose need to be addressed in order to use the n/p method. For the most part, this TBD did not sufficiently address the details and uncertainties of the n/p methodology.

In addition to the lack of details concerning the n/p method, the TBD did not sufficiently investigate and address other periods of neutron dose measurements and dose assignments from 1970 to the present, when TLD and CR-39 neutron monitors were used.

Some of the major areas of concern in neutron dose assignments for 1952–present include the following:

(1) The TBD (Thomas and Szalinski 2007) makes the following statement on page 13:

> *For neutron dose received prior to 1969, the dose should be adjusted by using a neutron to photon ratio. The ratio varied by operation and task. There was no comprehensive study of neutron flux at LLNL; the neutron to photon ratio cannot be established using existing data from LLNL.*

The fact that the n/p ratios cannot be established prior to 1969 using existing data from LLNL indicates that the dose reconstructor cannot adequately do a claimant-favorable neutron dose reconstruction for workers exposed to neutrons prior to 1969. The TBD then recommends using the SRS n/p GM value of 1.0, with a GSD of 3.0, and an upper 95th percentile of 6.1. This value used from SRS (Scalsky 2005) is, in turn, dependent on a study done at the Hanford site. The value is selected without any documented analysis or support provided in the TBD. Some of the problems with this using the single n/p value from the SRS are as follows:

a. No analysis was made of the similarities and differences between the three sites, which involved many diverse operations.
b. A single n/p value for all operations through the time period of 1952–1969 is not appropriate, especially in view of the changes that took place in operations and radiation knowledge/controls during this dynamic period at DOE facilities.
c. According to Table 5-14 of Rev. 04-E of the SRS TBD (Scalsky 2006, pg. 102), the HB line average n/p value was 1.29, with a range up to 3.1, and on page 104, it states that Brackenbush et al. (1987) reported the n/p value was 2 for F-areas. If LLNL Pu working conditions are shown to be similar to the ones at the SRS, then using a single n/p value of 1.0 does not appear appropriate.
d. An n/p value for highly-moderated neutron sources would be claimant favorable in most cases. However, exposure potentials at LLNL consisted of higher energy neutrons from 14 MeV D-T reactions, high-energy accelerators, and reactor neutron ports. This could create neutron fields with n/p values of up to 10:1, an order of magnitude greater than the recommended 1:1 value.

e. A brief search of available LLNL documents indicates that there are some neutron spectra and dose measurement information available that may be applicable to better define n/p values, and to characterize neutron fields and exposures at LLNL. A few examples are Myers and Prevo 1969, Griffith et al. 1977, Harrar 1976, and Griffith et al. 1984, among others that are available. The ORAU server Site Research Query Interface lists 146 documents concerning neutron-related topics at LLNL. LLNL personnel were very active in neutron dosimetry and related research, and published articles in the Health Physics Society Journal (among other noted journals), such as Straume 1985 (setting neutron radiation safety standards), Hankins 1978b (neutron remmeters and thermal neutron response), and Griffith et al. 1979 (developments in neutron dosimeters), just to list a few.

f. An abundance of publications by noted researchers at LLNL would indicate that there were some in-depth studies of neutron fields and doses at the LLNL that cover numerous years and various operations. A quick review of just the few articles mentioned above indicate that the researchers were involved in investigating a wide range of neutron energies, including thermal neutrons; sub-critical and critical-assembly neutrons; Cf and Pu spontaneous fission neutrons; (alpha,n) neutrons; D-T 14 MeV neutrons; and accelerator produced neutrons.

(2) Page 11 states that before 1963, the data were not adequately defined to directly report neutron doses, and that the dose reconstructor should use the guidance in OTIB-0023 (ORAUT 2005b) and PROC-0006 (ORAUT 2006b). This is an important statement and needs to be explained in detail. For example, what would be the effects of switching from the NTA film results to the n/p method on deriving the shallow dose?

(3) Information concerning the number of workers monitored for neutron exposure during the period from 1952–1969 needs to be provided. Although the dose reconstructor will not be using the NTA film results directly, this is an important item, because in many cases, the dose reconstructor will use this as a guide as to whether to assign neutron dose using the n/p method.

(4) It is stated that neutron dosimeters were calibrated using PuBe sources prior to 1970 and Cf-252 thereafter. There were a wide range of neutron energies at LLNL (Thomas and Szalinski 2007, pg. 11). Details are needed concerning dosimetry response using these calibration sources, compared to actual neutron fields found at various work locations and any benchmark neutron dose, energy, and n/p values measurements made in work locations.

(5) The effects of non-albedo neutron TLD dosimetry/calibration on recorded dose during 1969–1975 need to be investigated and discussed.

(6) Information concerning the number of workers monitored for neutron exposure after 1970 is needed, because it is only stated that they were monitored as needed, but no additional information or data has been presented to determine if this monitoring was adequate for neutrons for all locations and time periods at the LLNL and its related sites.

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(7) Information concerning n/p data or other methods that will be used for assigning neutron doses during gaps or to unmonitored workers for 1970–present and for use in a coworker's model needs to be provided.

(8) CR-39 neutron dosimetry has been used at LLNL since 1986. The TBD (Thomas and Szalinski 2007) needs to provide information concerning how this is integrated into the overall total neutron dose recorded for a worker at LLNL in conjunction with the TLD readings. It would also be helpful to provide information concerning what workers and their locations are monitored using CR-39 neutron elements and the advantages/ limitations of this technology in the neutron radiation fields at LLNL and its associated sites.

SC&A has concluded that the present TBD (Thomas and Szalinski 2007) does not provide sufficient details and quantitative data to support neutron dose reconstruction that is technically sound and ensures claimant favorability for all workers at the LLNL and its associated work locations for the period 1952–present. This is especially true for 1952–1969, when the use of the n/p method (using a single n/p = 1.0 from the SRS for all operations for all years) is recommended by NIOSH. The conclusion also applies to 1970–present, because the neutron badging policy has been very subjectively defined as those with "significant neutron exposure" were badged; it has not been shown that all workers exposed to neutrons were badged. Additionally, a valid neutron-dose coworker model for unmonitored workers has not been developed for 1970–present. There appear to be more documents and data available than have been presented and/or used in the current TBD (Thomas and Szalinski 2007) to construct a technically sound and claimant-favorable neutron dose assignment and coworker model.

5.12 LACK OF VALID EXTERNAL DOSE COWORKER APPROACH HINDERS ADEQUATE DOSE ESTIMATION FOR EARLY UNMONITORED WORKERS

Several times in the Occupational External Dose TBD (Thomas and Szalinski 2007), the subject of using coworker data is mentioned:

> [Page 10] *"If available, coworker data should be used."*
> [Page 17] *"…to apply a dose based on coworker data."*

However, the TBD does not provide any LLNL-specific photon, beta, or neutron coworker data/model/tables for use by the dose reconstructor in assigning dose to unmonitored workers; only a reference to LANL, Table 6E-2, is made on page 15. Also, to date, no TIB has been issued that covers unmonitored LLNL workers' external dose assignments using coworker data. Therefore, detailed information is needed that can assist the dose reconstructor in assigning external doses to unmonitored workers at LLNL for photon, beta, and neutron doses. Information to be considered in using coworker data are as follows:

(1) A table of recommended photon, beta, and neutron dose assignments for each year from 1952–present (as a function of categories of worker's location and/or job title, as is needed).

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(2) Details concerning the population of workers from which the data were drawn should be provided. Some useful information for each type of radiation would be:

- Number of badge readings included in each year's data
- Any filtering of data, i.e., "did not include readings less than MDL," etc.
- Work locations and job title categories of that are most prevalent in the coworker data
- Distribution of doses each year, including high, average/median, and low readings

(3) Information concerning the assignment of the appropriate percentile, such as 50th percentile for unmonitored workers with low exposure potential and 95th percentile for routinely exposed unmonitored workers.

SC&A concludes that the present TBD (Thomas and Szalinski 2007) does not present sufficient analysis, data, and dose reconstruction guidance to provide a valid coworker model for 1952–present for photon, beta, and neutron radiation. The reliance on LANL coworker photon and/or beta data is not supported by quantitative comparative analysis over time and job types. Additionally, because the dose data for LANL (NIOSH 2007) for 1943–1975 are presently under SEC-00051 (which indicates that NIOSH cannot estimate doses for LANL workers with sufficient accuracy), this dose data should not be applied to LLNL workers. The present TBD does not provide information and dose reconstruction guidance, such as a coworker model with data tables, for unmonitored workers with potential for exposure during the period 1970–present.

5.13 SECONDARY ISSUES

5.13.1 The Occupational Internal Dose TBD Lacks Information on Incidents that Could Cause Significant Intakes or External Dose

The lack of information on incidents that could have caused significant intakes of radionuclides could hinder accurate interpretation of bioassay results and identification of intakes by unmonitored or inadequately monitored workers.

The Occupational Internal Dose TBD (Berger and Szalinski 2005) states the following in Section 5.4, "Significant Incidents with Internal Dose Potential:"

> *During operation at LLNL, a number of incidents increased the potential for intakes of radioactive materials. If a claimant recalls involvement in one or more of those incidents, dose reconstructors can use the information in Table 5-7 as input to an incident-specific assessment. This list is not all encompassing, many other incidents probably occurred; these are the incidents identified from review of the data capture records. Individual claimant records may provide documentation of involvement in other incidents.*

There are only three incidents in Table 5-7 (Berger and Szalinski 2005) for covering the site history. It is difficult to understand how the dose reconstructors can use the information from only these listed incidents to help reconstruct a claimant's exposure from involvement in one of

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the "number of incidents" that have occurred at the site. If a claimant recalls involvement in an incident, then every attempt should be made to find out as much about that specific incident as possible through claimant interviews and available LLNL records. Interpretation of bioassay data can be assisted by the use of incident records information. The use of medical interventions for any major intakes that would have undoubtedly been associated with incidents (e.g., chelation for plutonium intakes) that are not discussed in this TBD may be found in incident records, and bioassay interpretation can be assisted by this information. According to a health physicist interviewed, there have been several chelations in the last 15 years. NIOSH needs to determine if an incident records review of greater extent needs to be performed, and to justify why it does not need to do this if it believes it is not applicable to reconstructing doses accurately. During interviews with site employees, a location identified for incident records retention was the Fire Station.

In a facility as large as LLNL, there most likely have been some incidents/accidents that need to be addressed in the TBD. This is especially true in the early days, before all the workers were badged and when there were many unknowns in experiments and in operations. The Occupational External Dose TBD (Szalinski 2005) does mention the following on page 13:

> *Specific incident reports might address significant nonroutine worker doses, such as skin contamination events. The dose assessments in such reports, based on investigations conducted at the time of the incident, should be the best estimates of dose received.*

However, the recently revised Occupational External Dose TBD (Thomas and Szalinski 2007) does not provide any information concerning the major incidents/accidents at LLNL and how they were handled, changes in policy resulting from these events, or what the resulting exposures were and if any unbadged workers were exposed. One example is the 1963 criticality accident in Building 110 (Montan 1963).

In its response to SC&A's internal dose section question #12 and question #7 of the site description section (see Attachment 3), NIOSH indicates that more research has been performed to better describe accidents and incidents in an ongoing revision of the LLNL TBD. This is an important effort that is needed for internal, external, and environmental dose assessment, which should be fully supported to quickly assist these dose assessments with appropriate claimant-favorable determinations. As discussed above, critical information for dose assessment accuracy can often be found in incident/accident investigation reports.

5.13.2 Occupational Medical X-rays Incompletely Characterized for Dose Estimation

The current guidelines, as presented in the reference OTIB-0006, Rev. 3 (ORAUT 2005d), go a long way in assuring that occupational medical exposures are included in determining the overall dose estimations for claimants. For instance, the LLNL Occupational Medical Dose TBD, ORAUT-TKBS-0035-3 (Turner 2005), refers the dose reconstructor to the previous Rev. 2 of OTIB-0006 (ORAUT 2003b). Unfortunately, the interpretation to date by ORAU in the Occupational Medical Dose TBD utilizing OTIB-0006, Rev. 2 (ORAUT 2003b) is not as claimant favorable as the guidance provided in OTIB-0006, Rev. 3 (ORAUT-2005d). The

Occupational Medical Dose TBD (Turner 2005) assumes an interpretation that also has been considered and applied at other sites, such as RFP and Hanford Plant. To this extent, the assumption that medical procedures are limited to only one pre-employment and other potential annual chest x-rays as part of routine physical exams may substantially underestimate worker medical exposure when evaluating the totality of occupational medical exposure. ORAUT-PROC-0061 (ORAUT 2006d, Table A-1, pg. 15) does indicate that when using the "Maximizing Approach," the dose reconstructor should assume a pre-employment and annual PA chest x-ray exposures. However, this claimant-favorable option is not applied in determining the "Best Estimate Approach" or the "Minimizing Approach" (ORAUT 2006d, pp. 8–10).

In support documentation OTIB-0006, Rev. 3 (ORAUT 2005d), it is concluded that other examinations may be included, such as special job exams (e.g., respiratory protection, beryllium workers, asbestos workers, etc.) and termination exams.

The Occupational Medical Dose TBD (Turner 2005) only mentions OTIB-0006, Rev. 2 (2003b). When revised, the TBD should lead the dose reconstructor to Rev. 3 of the OTIB-0006 (ORAUT 2005d). The following quote from the TBD does note that it is not feasible to address the three general approaches specified in PROC-0061 (ORAUT 2004c), and emphasizes the importance of consulting the employee's complete medical records to determine the worker's occupational medical x-ray exposure:

> *Chest films for beryllium and asbestos workers were apparently introduced in the 1980s with a frequency dependent on the age and exposure of the individual (Noonan 2002). Available documents indicate that chest X-rays were administered on an individual basis in keeping with acceptable guidelines of occupational medicine. In the absence of a general policy for frequencies of regularly required chest X-rays, it is not feasible to address the three general dose reconstruction approaches (maximizing, best estimate, and minimizing) specified in Occupational X-Ray Dose Reconstruction for DOE Sites* [ORAUT 2004b]. *Dose reconstructors must consult an employee's medical records to determine the extent of the worker's required medical X-rays.* (Turner 2005, pg. 6)

ORAUT 2004b has been updated to PROC-0061, Rev. 01 (ORAUT 2006d), which was issued after the publication of the Occupational Medical Dose TBD (Turner 2005).

When the individual medical record is lacking in specific information, the TBD offers no other default means to develop a realistic medical x-ray history that might also include special chest radiography for respirator certification, beryllium and asbestos workers, and food handlers which might be a part of the annual physical. There is nothing in the TBD that documents past medical protocols. Such special chest radiography was often performed separately, at the request of the Medical Department, until the mid-1980s.

The Occupational Medical TBD does point out the following:

> *Apart from the pre-employment baseline PA chest X-ray, it does not appear that LLNL mandated routine examinations on a regular basis for employees.* (Turner 2005, pg. 6)

However, unlike several other similar sites, the TBD provides no table that establishes the frequency of chest x-ray examinations. Table 3-1 in the LANL Occupational Medical Dose TBD (Johnson 2004, pg. 5) provides an example of this kind of table.

The TBD refers to a March 1991 LLNL Health Services Department Radiography Program report that states the following:

> *Requisition of X-ray studies for the purpose of diagnostic information should be based on clinical evaluation. Diagnostic X-ray examinations will be requested after an appropriate medical history and physical examination has been performed, in accordance with reasonable medical practice and occupational guidelines. Diagnostic objective, relevant medical history and X-ray procedure requested will be recorded on the radiographic request form. … Based on the unique nature of the work performed at LLNL, a pre-employment baseline PA [posterior–anterior] chest X-ray examination is required. This film may be done at the time of pre-employment examination or a copy of a previous film or report may be requested and kept on file. Medical surveillance programs may mandate periodic chest X-rays. Periodic chest X-ray examinations unrelated to job exposure will not be done routinely but may be ordered by the examiner if clinically indicated.* (LLNL 1991)

Another factor not discussed in the TBD is the potential for and impact of x-ray procedures utilized by medical authorities to do special screenings, and to evaluate the result of injury and trauma.

The Occupational Medical Dose TBD, therefore, implies that only one pre-employment baseline PA (posterior-anterior) chest x-ray examination was all that was routinely done. There is no mention or documentation that some LLNL workers might not have received one chest examination of a PA and LAT per year, which was mentioned at other sites and was probably limited to a small fraction of high-risk workers. This was documented in Table 3.1 in the LANL Occupational Medical Dose TBD (Johnson 2004, pg. 5), especially after 1992. To the contrary, there is ample evidence that chest x-rays were provided on a voluntary basis to nearly all workers, as part of routine physical examinations. The majority of workers had chest x-rays as a routine at DOE sites until the mid-1980s, when federal guidelines warning against routine screening were first being enforced.

After discussion with NIOSH personnel during a conference call regarding LANL, it was learned that NIOSH planned, at least for LANL personnel, to limit occupational medical exposure to those chest exams described above, and to assume all other exposure as part of worker background. SC&A believes such an interpretation is not claimant favorable to those most at risk. Our concern is that specified high-risk workers will likely receive compensation based upon a POC principally from exposure to radiation and beryllium. Second, all radiation provides

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some risk, and arguably, is somewhat cumulative. These are not normal workers and warrant consideration of all forms of work-related x-ray exposure to be claimant favorable. SC&A believes NIOSH should review its interpretation of included exposure, and should adopt a broader interpretation of medical dose, as provided in the OTIB-0006, Rev. 3 (ORAUT 2005d).

Thus, it is not considered claimant favorable to limit occupational medical exams to one pre-employment chest x-ray examination and not to account for some regularly administered annual chest x-rays, unless medical records and protocols clearly limit the use of radiography to a small fraction of workers, which was not the case until the mid-1980s. ORAUT-PROC-0061 (ORAUT 2006d) also indicates that "Additional chest x-rays were apparently introduced in the 1980s for beryllium and asbestos workers with a frequency dependent on the age and exposure of the individual."

5.13.3 Beam Quality, Filtration, and X-ray Tube Output are not Well Known

The LLNL Occupational Medical TBD (Turner 2005, pg. 7) points out that the earliest an in-house radiation survey of the Fisher X-ray machine was done by the LLNL Health Physics Group in 1975:

> *The earliest document (Graham and Williams 1975) describes results of an in-house radiation survey of the Fisher X-ray machine in the Medical Department by the LLNL Health Physics Group. Measurements gave an ESE of 19 mR [at a source-to-skin distance (SSD) of 157 cm], for a "typical" chest radiograph (100 kVp, 100 mA, 1/20 s).*
>
> *Beam collimation was deemed "satisfactory," although the position of the light spot used for centering needed correction. The results of the survey indicated that the facility was operating properly and had adequate shielding. No other information was found about other aspects of the facility, such as screens, grids, film types, and development parameters.*

An issue of concern is that the DCFs are derived using a default half value layer (HVL) of 2.5 mm Al for Type 1 units, in use from 1952–1980. Another issue is that the unit, in use from 1980-present, had added filtration of 4.0 mm Al, which is significantly higher than the maximum 3.5 mm Al taken from NCRP Report 102 (NCRP 1989, Table B.2). NIOSH believes that when no information is known about the energy spectrum, it is appropriate to use the Implementation Guide (NIOSH 2006) as a basis document. However, SC&A is not able to verify that information provided in LLNL 1991 is adequate to validate or support the assumption.

The Occupational Medical Dose TBD, ORAUT-TKBS-0035-3 (Turner 2005), states the following regarding the application of ICRP Publication 34 (ICRP 1982) in developing DCFs appropriate for organ dose, and provides a default value for beam quality.

> *The ICRP tables were developed under the assumption that the primary X-ray beam is collimated to the image receptor size. The application of these DCF tables to the early X-ray machines, particularly before about 1970, must therefore*

> *be made in a way that compensates for the lack of collimation. Claimant-favorable allowance for this circumstance during different periods in the past, based on ICRP (1982), has been assessed in the generic document by ORAUT* [2003b], *which will be applied to estimate doses from the Fisher machine. In addition, when other data are not available,* [ORAUT 2003b] *recommends that the following values be used to express beam quality in terms of the half value layer of Al: 2.5 mm prior to 1980 and 4.0 mm for subsequent years. The ICRP (1982) values Document No. ORAUT-TKBS-0035-3 Revision No. 00 Effective Date: 08/22/2005 Page 9 of 13 are used directly to obtain the organ doses for examinations with the Xonics and Bennett systems in Table 3-1.* (Turner 2005, pg. 8)

In calculating organ dose, the TBD provides the following guidance.

> *Tables of DCFs are given in ICRP (1982) for seven organs in an adult anthropomorphic phantom for a number of common radiographic examinations with beams of different quality. For the PA chest projection, a source-to-image distance (SID) of 183 cm (72 in.) and an image receptor size of 35.6 × 43.2 cm (14 ×17 in.) are used. For an organ not included in ICRP (1982), but needed for the Interactive RadioEpidemiological Program (IREP), the DCF is taken to be that for the anatomically closest organ in the ICRP tables.* (Turner 2005, pg. 8)

Table 3-1 of the Occupational Medical Dose TBD, ORAUT-TKBS-0010-3 (Turner 2005), provides a very useful summary of the four types of x-ray equipment used at LLNL, and provides nominal operating parameters. These are documented by appropriate references for each type of machine. But as noted above, there is no other information on such aspects as screens used, grids, film types, and changes in developing parameters. It may be appropriate for NIOSH to search and add additional available references to help substantiate information depicted in Table 3.1.

The ORAUT 2003b guidance recommends that the following values be used to express beam quality in terms of the HVL of Al: 2.5 mm prior to 1980, and 4.0 mm for subsequent years. The ICRP (1982) values are used directly to obtain the organ doses for examinations with the Xonics and Bennett systems in the LLNL Occupational Medical Dose TBD (Turner 2005, Table 3-1, pg. 7).

An issue of concern is that the DCFs are derived using a default HVL of 2.5 mm Al for Type 1 units, in use from 1952–1980. Another issue is that the unit, in use from 1980-present, had added filtration of 4.0 mm Al, which is significantly higher than the maximum 3.5 mm Al taken from NCRP Report 102 (NCRP 1989, Table B.2).

NIOSH believes that when no information is known about the energy spectrum, it is appropriate to use the Implementation Guide (NIOSH 2006) as a basis document. However, SC&A is not able to verify that information provided in LLNL 1991 is adequate to validate or support the assumption. It may be appropriate for NIOSH to search and add additional available references to help substantiate information depicted in Tables 3.1 of the Occupational Medical Dose TBD, ORAUT-TKBS-0035-3 (Turner 2005).

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5.13.4 Reliance on ICRP Publication 34 for Applicable DCFs May Underestimate Dose

The TBD does consider the potential contribution to organ dose by using the DCFs for use by dose reconstructors for selected exams or specific organs in Table 3-4 on page 10 (Turner 2005). Organ dose equivalents for 14" x 17" PA chest radiography are provided for selected organs and for the different time periods for each type of x-ray machine used. This does not, however, take into account, the uncertainties in dose based on actual recorded measurements from the x-ray machine type, unless that information is available in the individual medical record. Unresolved is the concern that the DCFs are derived from ICRP Publication 34 (1982) and, therefore, are not comparable in terms of beam quality, which varies from unit to unit. These factors can contribute greatly to the dose to the chest and other organs for units in operation prior to 1960, where little documentation exists.

For the Fisher Machine used at LLNL from 1952 until the end of 1980, the TBD (Turner 2005, pg. 9) states the following:

> *In the absence of earlier documentation, the pre-1970 default values for organ doses given in Table 3-3 for the period 1952 through December 1969 are taken from Table 4.0-1 of ORAUT* [2003b]. *For January 1970 through December 1980, when the Fisher machine was probably retired, the doses in Table 3-3 are based on the default values from ORAUT* [2003b] *for this time period and scaled to be consistent with the 1975 measurements of Graham and Williams. Since the latter work showed the entrance kerma to be 0.020 rad and the default value is 0.10 rad for this time period, the doses given in column three of Table 3-3 are scaled to one-fifth their respective values in Table 4.0-1 of ORAUT* [2003b].

The TBD is deficient in that little documentation exists to validate x-ray protocols, equipment maintenance, and upkeep records prior to 1960. It uses information derived from the OTIB-0006, Rev. 2 (ORAUT 2003b) to estimate dose impacts. Further dose estimations are derived from Publication 34 (ICRP 1982) and NCRP Report 102 (NCRP 1989), and are not reflective of equipment and protocols used at LLNL during 1952–1960.

The TBD provides the following information about the Xonics System that replaced the Fisher units around January 1981.

> *No measurements were located that document the ESE for the Xonics chest exams at earlier times, from its beginning in January 1981 until the August 15, 1990, survey. In the absence of data to the contrary, the claimant-favorable assumption is made that the ESE was 0.045 R and the skin entrance kerma was 0.045 rad for the entire second period in Table 3-1. Thereafter, from November 1990 until its replacement after September 1992, the ESE is assumed to be 0.015 R and the entrance kerma, 0.015 rad. No records were found in which this level was exceeded. Table 3-3 lists the organ doses using these two values for the kerma and ICRP (1982).*

For the Xonics System used after January 1981 and the Bennett System used after 1992, NIOSH and ORAU indicated (see Attachment 3, pg. 7) that adequate information was available after 1980 to assess the skin-entrance kerma. The skin-entrance kerma assessed then allows for the appropriate use of DCFs that are provided in ICRP 1982.

Uncertainty is defined in the TBD as being due to measurement error. This uncertainty includes variations in kilovoltage, tube current, timers, and the source-to-skin distance (SSD). This approach is quite similar to the uncertainty analyses documented in other DOE site profiles. The conclusion in this TBD, and others, is that an uncertainty factor of +30% should be used by dose reconstructors.

SC&A agrees that the Occupational Medical Dose TBD conservatively estimates these essential aspects of an uncertainty review. Unresolved is the contribution to uncertainty in dose, due to other errors introduced by lack of quality controls in processing equipment and lack of adherence to established standard operating procedures (SOPs). A reasonable estimate of these contributions to uncertainty would be an evaluation of retake rates per examination type. As part of its revision of this TBD, NIOSH should revisit the potential for increased retake rates and evaluate its potential effect on dose.

The Occupational Medical Dose TBD does not show that LLNL applied dose minimization principles to reduce medical exposures prior to 1960. The document also does not assess or consider the likely exposure to workers who are referred to offsite medical facilities for followup. The TBD states that review of selected medical records and files did not reasonably show or match expected x-ray exam frequency, and type of exam. Little evidence exists to document the number of x-ray exams provided to the average worker, or for special exposure needs.

5.13.5 Lack of Maintenance, Collimation, and X-ray Protocol Data Increase Uncertainty

The Occupational Medical Dose, ORAUT-TKBS-0035-3 (Turner 2005), does not address the potential use of other forms of radiation exposure, other than x-ray units, that might have been used during medical injury diagnosis. This may involve use of isotopes, sealed sources, etc. The TBD is also deficient in that it does little to catalog the number, types of x-ray equipment, frequency of use, etc. The TBD also fails to document that available x-ray units were not operated at greater than 80–90 kVp during January 1981 while the Xonics x-ray machine was used, and for the Upgraded Sonics system used for chest x-rays from November 1990 to September 1992. Table 3-1 on page 7 does indicate that the Fisher x-ray machine was operative at 100 kVp during the period 1952 to December 1989, and that the Bennett x-ray machine was operated at 110 kVp from October 1992-present.

The TBD does not address LLNL efforts to perform routine and preventative maintenance, which suggests that routine maintenance of x-ray units is not likely, unless performed by an outside contractor. The lack of discussion of any routine maintenance dose on x-ray equipment, especially in the early days prior to FDA x-ray inspections that started in August 1960, leaves some doubt about what was done to ensure optimal operations and dose reduction prior to 1960.

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This is especially true for the Picker x-ray machine used for chest x-rays from 1952–1980. The TBD does mention that there is more information regarding the Xonics System used after 1980:

> *However, reports from an FDA survey on August 15, 1990 (Van Pelt 1990), and from the follow-up by LLNL (Noonan 1991) provide considerable detailed information. The survey tested an array of items and resulted in a number of suggested action items. One concern was the finding that the ESE measured with a phantom for chest X-rays was 45 mR. Subsequent improvements upgraded the Xonics system in a number of ways, as noted in Table 3-1. The ESE was reduced to a reported range of 11 mR to 15 mR (Winstanley 1990a, b), which was verified by the FDA survey of the following year (Thomas 1991).*

Table 3.1 on LLNL x-ray equipment (Turner 2005, pg. 7) does indicate, however, that the unit had "…satisfactory collimation, measured ESE = 19 mr at SSD =157 cm…" This leaves in question the quality of the safety-related procedures in the period from 1952 to 1989. The TBD does provide the following statement regarding safety-related procedures:

> *Detailed records were made for all X-ray examinations. The records include identification of the individual, the type of examination, data on operating parameters for the procedure, and other pertinent information. It appears that a single PA chest projection was standard practice. Radiographs are archived at LLNL and can be consulted.* (Turner 2005, pg. 6)

The lack of defined protocols and basis for approval of radiography procedures suggests that the use of radiography was not closely controlled. The Occupational Medical Dose TBD does not discuss the use of portable radiography to perform screenings and the potential for exposure of medical personnel or other workers without dosimetry devices being utilized. Interviews with past medical staff do suggest that portable x-ray units were not used. The TBD states the following in regards to the possible use of any PFG units at LLNL:

> *There is no evidence that fluoroscopy was ever used at LLNL for required medical examinations. A random sample of X-ray portfolios was selected from the archives and examined for seven individuals employed at LLNL in the 1950s and 1960s. No small-format films were found.* (Turner 2005, pg. 6)

A random sampling of only seven individuals' medical records seems to SC&A to be insufficient to rule out the possible use of PFG examinations at LLNL. The TBD provides no substantive documentation that PFG units were not used at that site from 1952 to 1960. Photofluorography units were not considered when organ dose calculations were documented in Publication 34 (ICRP 1982) and NCRP Report 102 (NCRP 1989), which forms the basis for organ dose calculations presented in the TBD, when documented use of an x-ray unit is available. The recently revised version of OTIB-0006, Rev. 03 (ORAUT 2005d), suggests that 3.0 rem per PFG exam is more appropriate. If LLNL medical records do, in fact, show evidence of the use of PFG exams from 1952–1960, then the TBD should be updated to ensure that the claimant is given the claimant-favorable dose of 3.0 rem for each PFG examination received.

The TBD also fails to document that available x-ray units were not operated at greater than 80–90 kVp during January 1981, while the Xonics x-ray machine was used, and for the Upgraded Sonics system used for chest x-rays from November 1990 to September 1992. Table 3-1 on page 7 does indicate that the Fisher x-ray machine was operative at 100 kVp during the period 1952 to December 1989, and that the Bennett x-ray machine was operated at 110 kVp from October 1992 to present.

The Occupational Medical Dose TBD, ORAUT-TKBS-0035-3 (Turner 2005), does not consider dose impacts due to less than optimal use of technology, such as using screens, grids, or bucky systems. The TBD does not consider these elements as potential contributions to uncertainty.

Also, the older version of the OTIB-0006, Rev. 2 (ORAUT 2003b), upon which the TBD relies, uses retake rates that average about 3%. The study referenced was based upon a large metropolitan hospital using highly trained technicians and well-maintained x-ray and processing units. A comparison review of federal facilities, such as by the Department of Defense (DOD) during the 1970s, using lesser-trained technicians (federal regulations did not require technician certification), showed that retakes sometimes ran up to 30% for abdominal exams, and often over 15% for chest radiography. The TBD fails to provide any substantive documentation about what retake rate was needed with the specific x-ray machines used at LLNL. Although the PFG, by design, is less likely to require retakes, it is inherently much more dose-intensive.

The conclusion is that the Occupational Medical Dose TBD does little to reasonably document the variety of medical occupational exposures and type of routine maintenance performed on the x-ray units up until 1960. Therefore, it is difficult to assure that a conservative and claimant-favorable estimation of dose is possible. This circumstance would suggest the need to reconsider a worst-case approach to establishing dose.

5.13.6 Gaps Exist in the Occupational Environmental Dose TBD

The LLNL Occupational Environmental TBD (Thomas 2005) provides internal and external dose information to be assigned to workers who were not monitored for external or internal exposure. The *Technical Information Bulletin – Assignment of Environmental Internal Dose for Employees not Exposure to Airborne Radionuclides in the Workplace*, ORAUT-OTIB-0014 (ORAUT 2004a), provides additional information on when environmental dose should be assigned:

> *If specific work locations on the site are unknown, dose reconstructors should always apply maximizing assumptions unless there is clear evidence (e.g., through the job description) that the maximum does not apply. As described in the previous section, however, an uncertain work location lessens the credibility of assigning environmental doses versus workplace internal doses. If work locations varied routinely (e.g., mail carrier, security guard), it might be appropriate to apply a site-wide average, if available, or use a weighted average based on the percentage of time in various locations.* (ORAUT 2004a)

The LLNL Occupational Environmental TBD, ORAUT-TKBS-0035-4 (Thomas 2005), includes exposure from airborne releases, ambient external dose, and ingestion of tritium-contaminated water.

> *The TBD describes the estimated annual intakes for inhalation exposure and estimated radiation dose as a result of ambient exposures at LLNL. Environmental measurements do not distinguish the source of emissions and, therefore, will reflect air concentrations from nearby as well as distant sources. The estimates of emissions were useful in filling in some gaps in measurement data and were critical to estimating exposure before the start of comprehensive and routine measurement data reports.* (Thomas 2005)

The TBD discusses the Main Laboratory area (hereafter referred to as the Livermore site) and Site 300 separately, which is appropriate, since Site 300 is 15 miles east of the Livermore site. Operations began at the Livermore site in 1952 and at Site 300 in 1955. Methodologies for assessment of internal dose are available from 1961 forward. External dose reconstruction data is available from 1976 forward, with assumed dose contributions made for previous years. Drinking water data is available for the Livermore site, but has not been located for Site 300.

The Environmental Dose TBD has not included a methodology to calculate doses from environmental exposures in the early years when exposures may have been higher, but the TBD indicates that such an assessment of environmental dose was done. No consideration was given to increased effluent controls and improved equipment, and how this may affect the application of estimates from one year to another. The TBD did not consider data available regarding episodic releases, soil contamination, contributions to environmental dose from other DOE sites [e.g., Sandia National Laboratory - Livermore (SNLL), NTS, PPG], and internal exposure from radionuclides other than plutonium, uranium, and tritium.

5.13.6.1 Environmental Dose in the Early Years

The highest internal exposures likely occurred during the early years of operation, and decreased with time as increased controls and better equipment were implemented. The LLNL Environmental Dose TBD (Thomas 2005) indicates that air samples were established as early as 1961 for the Livermore site and 1962 for Site 300. Air samples were analyzed for gross alpha and gross beta initially. In 1971, isotopic analysis for plutonium, tritium, and uranium began. From 1961–1971, analysis was limited to gross alpha and gross beta. Tritium intake values prior to 1972 are not available, and gross alpha and beta are not available prior to 1961 in the TBD. The TBD is only appropriate for estimation of dose from 1961 forward for plutonium and uranium, and 1972 forward for tritium. In a number of cases, actual concentrations for isotopic values were not available, so the maximum result for a different year was assigned (Thomas 2005).

NIOSH previously indicated that efforts are in progress to develop values for uranium and plutonium prior to 1961, and tritium prior to 1972, and that this data may be presented in future revisions of the TBD. In response to SC&A's question regarding the progress on development of a pre-1972 model, NIOSH stated the following (see Attachment 3):

***NIOSH Response:** Environmental air monitoring samples were not analyzed for tritium prior to 1972. Most of the tritium released was airborne with the dominant source being the Tritium Facility (Building 331, previously Building 172) which began operation in 1952. The TBD was revised to estimate inhalation of tritium by using dispersion models that were developed by LLNL to support a dose assessment after a release of tritium in 1970. Using the dispersion calculations that were performed in 1970, the estimated annual release of 200 TBq/year and the same weather conditions that existed during the release, the concentration of tritium is estimated to range from 5.8 Bq/m^3 to 2 x 106 Bq/m^3 for any given year, from 1952 to 1971. It is unreasonable to assume that any one person stayed in the exact location (immediately downwind of the Building 331 stack) for the entire exposure period of twenty (20) years, that the weather conditions did not remain stable and consequently, or that the maximum concentration represents the potential exposure. Revision 01-E (June 26, 2006) provided these data in Tables 4-3 through 4-7. Using the maximum airborne radionuclide concentration in a year (from either actual data or an estimated value), annual intakes for the radionuclides of concern were derived by using an assumed individual's annual respiration rate of 2,400 m^3/yr.*

The revision discussed above is not included in the currently available LLNL Occupational Environmental Dose TBD. This leaves a substantial gap for determining environmental dose in the early years. No methodology has been proposed to mitigate this situation.

Perimeter or onsite outdoor air sampling is used as the basis for determination of environmental internal dose in the TBD. Other sources of data exist that may be beneficial to the determination of internal environmental dose. In some cases, environmental data may be classified (e.g., 1965 tritium release report, environmental data from testing). Sources of environmental monitoring data, such as stack release data, have not been considered in the evaluation of early doses. According to the Hazards Control Manual Part I, Procedure 802 (LLNL 1961), each area potentially emitting airborne material was required to maintain a continuous stack-monitoring program:

Each area potentially capable of emitting enough airborne material to exceed the permissible off-site concentrations despite the dilution factor attributable to the distance from the stack to the site boundary fence shall maintain a continuous stack sampling program. Continuous monitoring equipment is currently required for the following areas:

Building 110 – Criticality test cell exhaust
Building 121 – Hot cell exhaust
Building 171 – Enclosure and room exhaust
Building 172 – Enclosure and room exhaust
Building 190 – Cave exhaust systems
Building 193 – Reactor room exhaust

> *The Hazards Control monitor assigned to the area will record the average daily reading of the stack monitors in a separate log book reserved for this data (LLNL 1961).*

Furthermore,

> *The stacks of other buildings where radioactive materials may escape in the effluent shall be surveyed at least once each month by swipe sampling of the stack interiors or with air sampling equipment. (LLNL 1961)*

During the 1965 tritium release, Building 331 (formerly 172) air exhausted through a stack that was monitored continuously by a Keithley Electrometer and recorded on a strip chart (Peterson et al. 2002). It appears that effluent monitoring capabilities were in place for the earlier years, although the technology may not have been as advanced. This data may be beneficial in bounding environmental doses prior to when air-sampling data became available.

There is some question regarding the adequacy of the air monitoring data. In 1990, the Tiger Team raised concerns regarding the placement of environmental air samples:

> *Some of the air samplers, Main Site perimeter and community, were located in areas obstructed by buildings, tress, and other obstacles which prevents them from getting a representative sample of ambient air* (DOE 1990).

This should be given some consideration in the TBD, particularly when determining uncertainty.

Nolan (1958) indicated all LLNL employees wore some form of external radiation dosimetry starting in March 1958. The TBD indicates limited data were available for the determination of external environmental dose prior to 1976:

> *From 1976 to the present, thermoluminescent dosimeters (TLDs) were used in determining ambient radiation levels, including natural background (terrestrial and cosmic) radiation. TLDs were deployed at Site 300 in July 1988.* (Thomas 2005)

Implementation of CaF2:Dy chip dosimeters pre-dated 1976, and exposure information is available in the early 1970s. The evaluation of ambient external exposure did not make use of this data. Additional data that were not considered in the TBD analysis was ambient neutron exposure. Data are available for periods of time when neutron dosimeters were included in the environmental monitoring program. The primary source of potential neutron exposure was the 14-MeV neutron generator (Building 212).

During the years 1952–1958, LLNL was actively involved in weapons research and testing, as well as accelerator and reactor development. In 1958, the moratorium on nuclear weapons tests began and continued into 1961. This redirected LLNL's operational mission. Without the availability of external monitoring data from 1952–1958, when personnel monitoring was not widely implemented, it is difficult to reconstruct potential external exposures during these years.

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Assignment of dose from later years should be examined carefully, considering changes in mission and the improvement in technology and equipment over time. The reliance on radiation exposure at the perimeter is not necessarily representative of the exposure received by onsite workers. Representativeness of the monitoring sites in relation to the location of the source and the employee deserves some treatment in the TBD.

5.13.6.2 Internal Exposure from Radionuclides Other than Plutonium, Uranium, and Tritium

Several radionuclides of concern are not included in the TBD, and no analysis has been done to determine whether these other radionuclides contribute to specific organ doses. The LLNL Environmental Dose TBD describes the types of radioactive material encountered at LLNL:

> *Throughout its history, LLNL has processed and handled a variety of radionuclides, including uranium and transuranic elements, mixed fission products, and accelerator-produced radionuclides.* (Thomas 2005)

In *Environmental Report for 1989 Lawrence Livermore National Laboratory* (Gallegos 1989), the potential radiological environmental pollutants at the Livermore site are listed as gross alpha, gross beta, gamma isotopes, plutonium, K-40, radium isotopes, thorium-232, tritium, and uranium isotopes. Isotopic analysis of soil samples concentrated on the evaluation of Pu-238, Pu-239, and Sr-90. Radioactive effluent data are available for Ar-41 from at least the early 1970s forward (Griggs et al. 1985). The 1973 environmental report indicates a release of 1,300 Ci of Ar-41 from the 3 MW pool-type reactor (Silver et al. 1974). Argon-41 has been identified as a key source of environmental exposure in other site profiles. Effluent data also exist for N-13/O-15 from at least the early 1970s forward. The source of these emissions is the electron-positron linear accelerator (Griggs et al. 1985).

Gross alpha and gross beta air concentration data are available for the Livermore site and Site 300 for the period 1961–1971. The TBD indicates that for the Livermore site, the gross alpha concentration is used to calculate the presence of Pu-239 and U-234. For Site 300, the gross alpha concentration is used to calculate the presence of U-235 and U-234. The assigned dose is selected from the higher of the two calculations. The gross beta concentration for the Livermore site and Site 300 is assumed to be Th-234.

As previously mentioned, thorium was used in hydroshots at Site 300. Much of the buried waste was sent to Site 300 for disposal, along with waste from LBNL. The waste streams include radionuclides such as tritium, uranium (e.g., U-232, U-233, U-234, U-235, U-238), fission products, activation products, plutonium (e.g., Pu-238, Pu-239), thorium (e.g., Th-228, Th-230, Th-232, Th-234), accelerator-produced radionuclides, and transplutonium elements. Transplutonium elements have greater specific activities, shorter spontaneous fission half-lives, and more photons per disintegration (Denham 1969). Much smaller quantities of these elements produce the same exposure as Pu-239. No mention is made of the explosive burn pits at Site 300 or if these operations involved radionuclides; at other DOE sites, there was often some level of uranium associated with this activity.

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ORAUT-OTIB-0014 (ORAUT 2004a) indicates a diminimus value for environmental dose as a part of processing a claim:

> *Calculated annual environmental internal doses that total less than 1 mrem for a specific radiation type and energy interval (for photons and electrons) are not required to be included in the Interactive RadioEpidemiological Program (IREP) input sheet.* (ORAUT 2004a)

This would infer that doses in excess of 1 mrem for a specific radiation type and energy interval should be included in the dose reconstruction. Some analysis of potential dose from radionuclides other than Pu, U, and tritium should be conducted to ensure that dose from other radionuclides meets the diminimus dose value.

5.13.6.3 Environmental Exposure Sources Not Considered

Episodic Releases

Accidental releases have resulted in large amounts of radionuclides released to the environment. An accidental release of 350,000 curies of tritium gas occurred on January 20, 1965, from the Tritium Facility (Building 331, previously Building 172) (Peterson et al. 2002). In 1970, 289,000 curies were released to the surrounding environment. On April 12, 1971, an accidental release of 240 Ci of tritium occurred from the Gaseous Chemistry Building. Extensive follow-up sampling was conducted post-event to evaluate the effects of this release on the environment (Gudiksen 1971). Another accidental release of 5,000 Ci of tritium occurred on June 8, 1984. The 1965 and 1971 tritium releases accounted for about 80% of the tritium released from LLNL, which is not included in the current analysis of tritium exposure in the TBD. On March 26, 1963, a nuclear excursion took place at the critical experiments facility. Air, vegetation, and soil samples obtained within hours after the incident indicated a release of small amounts of short-lived, high-yield gaseous fission products and their daughters (Kathren et al. 1964). Other episodic releases included release of plutonium, americium, and curium to the soil. Episodic releases require some evaluation to ascertain if they have been captured by environmental monitoring available at the time, and what the relative impacts are on the total environmental dose.

Soil Resuspension

The LLNL Occupational Environmental TBD, ORAUT-TKBS-0035-4 (Thomas 2005) indicates that exposure may have been received from the resuspension of radionuclides in soils:

> *Occupational environmental dose refers to exposure received by workers outside the facilities at the Lawrence Livermore National Laboratory (LLNL) from elevated ambient radiation, from facility discharges to the environment, and from resuspension of radionuclides in soils.* (Thomas 2005)

Furthermore,

> *There was a potential for ingestion of radioactive materials from resuspension of radioactive materials (Section 4.3)….* (Thomas 2005)

Little discussion is offered on how dose from resuspension of radioactive material will be treated. In their response to SC&A's question regarding ingestion and soil resuspension factors, NIOSH indicated the following:

> ***NIOSH Response:*** *The potential for environmental dose was solely evaluated for the inhalation pathway; there was no assessment of the ingestion pathway. The current TBD addressed what was believed to be the major contributors to exposure, but as additional information becomes available and if it indicates modifications are warranted, information will be added to the TBD for use by dose reconstructors.*

Furthermore,

> ***NIOSH Response:*** *There was no assessment of the ingestion pathway. No soil resuspension factors are available at this time.*

Based on NIOSH's response, it is apparent that the potential for environmental dose was solely evaluated for the inhalation pathway, and there was no assessment of the ingestion pathway. The Occupation Environmental Dose TBD should be edited to reflect the actual pathway evaluated.

An evaluation of exposure from resuspension of contaminated soil should be added to the TBD for completeness. Environmental monitoring reports indicate that soil characterization at LLNL was conducted in 1971 and 1972. Soil samples collected from Site 300 showed greater than background concentrations of U-238 in areas near the firing table (Griggs et al. 1985). Soil samples were also collected at the Livermore site, and are presented in annual environmental reports (Silver et al. 1974, Gudiksen 1971, Gudiksen et al. 1972). Data is available to conduct some level of analysis at both the Livermore site and Site 300. Some onsite soil contamination was identified in both locations.

Environmental Dose Contributions from Onsite Sources

There has been no consideration of potential releases from the Decontamination and Waste Treatment Facility or other waste treatment and storage facilities (e.g., Buildings 280, 693, 695). Site experts have indicated that there were sources of environmental exposure from the "taxi strip." In the early years of the Laboratory's operation, the taxi strip of the former naval air station was used for storage of liquid waste. The goal was to evaporate the liquid waste in open vats, and reduce it to a near solid form. Plastic- and concrete-lined trays for evaporation of low-level liquid waste leaked and penetrated several feet into the ground at the old taxi strip. This area was remediated (excavated) in the early 1980s to eliminate the contamination. Radium was identified during aerial surveys of the site in areas where the military buried radium dials when they had ownership of the site (see Attachment 2).

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Environmental Dose Contributions from Other DOE Facilities

The Sandia National Laboratories, Livermore (SNLL) is located immediately south of LLNL. SNLL is under contract with the DOE to provide R&D associated with nuclear weapons and security tasks. LLNL and SNLL are separate facilities and maintain independent monitoring programs (Gallagos 1989). The TBD does not discuss the contributions to environmental dose from releases at the adjacent SNLL.

The TBD does not indicate whether there was opportunity for unmonitored workers to receive environmental exposures at the testing sites (e.g., PPG, NTS, Amchitka, etc.) The environmental source terms would differ from those encountered at the laboratory sites, including radionuclides, such as iodine and other fission products.

Methodologies have not been proposed for how to assign environmental dose in the era when monitoring data are not available. The Environmental Dose TBD does not make use of available effluent and external radiation data, as a result of limiting the evaluation to publicly available documents. Environmental neutron dose were not considered, although monitoring was done in some years. The TBD does not consider data available regarding episodic releases, soil contamination, contributions to environmental dose from other DOE sites (e.g., SNLL, NTS, PPG), and internal exposure from radionuclides other than plutonium, uranium, and tritium. Although the TBD indicates that 90% of the environmental dose was received from plutonium, uranium, and tritium, there is no analysis to support this assumption. Radionuclides, such as noble gas, fission products, and N-13/O-15, are not evaluated for their potential contribution to environmental dose. The impacts of these issues on claimant exposure are minimal in comparison to occupational internal and external exposure; however, incorporation of additional information will make the TBD more accurate and complete.

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

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

6.1 SATISFYING THE FIVE OBJECTIVES

The SC&A review procedures, as approved by the Advisory Board, require that each site profile be evaluated against five measures of adequacy: (1) completeness of data sources, (2) technical accuracy, (3) adequacy of data, (4) site profile consistency, and (5) regulatory compliance. The SC&A review found that the NIOSH site profile (and its constituent TBDs) for LLNL represents an adequate accounting of the primary internal issues related to plutonium, uranium, and HTO or gas exposures, as well as main external hazards from the reactor and accelerator facilities. The LLNL site profile falls short in fully characterizing a number of key underlying issues that are fundamental to guiding dose reconstruction. In some cases, these issues may impact other site profiles. Many of the issues involve lack of sufficient conservatism in key assumptions or estimation approaches or incomplete site data or incomplete analyses of these data. Section 6.0 summarizes the key issues. Detailed evaluation of these issues is provided elsewhere in the report.

6.1.1 Objective 1: Completeness of Data Sources

The breadth of data sources used as a basis for the LLNL site profile is evident in the 144 references in the TBDs and the 876 documents for LLNL in the OCAS Site Profile Research Database. The NIOSH/ORAU team consulted health physics personnel with long histories at LLNL who have extensive knowledge of key dosimetry historical processes and personnel monitoring data. For the LLNL site, these typically contain hardcopy internal and external monitoring results. The individual monitoring data provided to NIOSH, as cited by the site profile and applied in dose reconstruction, are pulled from these records at LLNL.

Completeness and accuracy of the data used in dose reconstruction is likely lacking, particularly for internal exposure. The test group, from the laboratory responsible for the design of weapons, sent hundreds of personnel to the test sites for testing preparation, detonations, recovery of data and materials post-detonation, and support functions (including radiological safety). Although external monitoring was provided by REECo, Eberline, or DOE-Nevada, it is unclear how NIOSH identifies those with potential exposure at test sites when they request data from DOE-Nevada, and how dose reconstructors are to interpret this data.

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The site profile provides no explanation for how dose reconstructions will be handled in cases where dose reconstruction cannot be done, as previously identified by NIOSH in other technical documents, nor do they provide reference to other TBDs that may assist the dose reconstructor in interpreting data collected from the testing site. No reference is made to how internal and external dose reconstruction will be completed for test sites without TBDs. Source term descriptions do not appear to have considered information in classified documents.

6.1.2 Objective 2: Technical Accuracy

The site profile does not adequately address data insufficiency for impact and implications to early worker dose reconstruction. Information available for dose reconstruction in the early years is limited, inadequate, or in some cases, not available. The Oak Ridge Associated Universities Team (ORAUT) has recently produced several new ORAUT TIBs and PROCs that have application to LLNL (e.g., OTIB-0065, (ORAUT 2007e), an LLNL-specific document with coworker guidelines for internal dose. These TIBs and PROCs assist the dose reconstructor in developing more claimant-favorable doses. However, a similar TIB for LLNL external coworker dose has not been developed and is needed. Since there is a lack of bioassay data prior to 1958 and serious difficulties identified for reconstruction of internal dose at testing sites, it will be important for the LLNL TBDs to be updated to highlight the importance of utilizing these OTIBs and PROCs during the claimant's dose reconstruction.

The Occupational Internal Dose TBD, ORAUT-TKBS-0035-5 (Berger and Szalinski 2005), has a number of deficiencies related to inadequate consideration of exposure and missed dose. Radionuclides used at LLNL were not always monitored using bioassay, and this makes it difficult to find the data needed for claimant-favorable dose reconstruction. Exposure to a number of these radionuclides was not given adequate, or in some cases, any consideration in the internal dosimetry TBD, although some are listed as facility-specific radionuclides handled in particular technical areas. The completeness of results for uranium, tritium, and plutonium for the early years at the site is uncertain.

Numerous "secondary" radionuclides have been handled at LLNL in varying quantities. These have included radium, Th-228, Th-232, Am-241, U-233, Cm-244, Cf-252, Pu-238, C-14, Na-22, P-32, S-35, I-125, I-131, Sr-90, N-13, O-15, fission products, activation products, and others. A lot of bioassay data in the database are identified as gross alpha and gross beta results, and NIOSH has not identified which, if any, of these secondary radionuclides may be associated with these data. These radionuclides may result in significant organ doses that are neglected. Reliance on partially validated bioassay data and claimant interviews to identify intakes from secondary radionuclides does not provide a sound basis for determining which individuals received dose from secondary radionuclides. Further research into the potential exposures from these radionuclides is needed to determine which workers may have been exposed, the quantities they were exposed to, and the potential internal doses from intakes. A proposed method, however, for identifying individuals potentially exposed to many of these radionuclides and assigning them a missed dose is absent from the TBD. Table 5.1 (Berger and Szalinski 2005, pp. 9–13) does provide source terms by building (activity fractions) for a large number of radionuclides. There is limited guidance, however, on how to apply these activity fractions.

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The LLNL Internal Dose TBD, published in 2005, lacks the benefit of making reference to ORAUT-OTIB-0066 (ORAUT 2007g), which provides more recent guidance on calculation of dose from intakes of special tritium compounds; ORAUT-OTIB-0049 (ORAUT 2007b), which provides guidance on plutonium strongly retained in the lung (high-fire plutonium intakes); and ORAUT-0060 (ORAUT 2007c), which provides guidance for internal dose reconstruction.

The current methodology outlined in ORAUT-TKBS-0035-6 (Thomas and Szalinski 2007) may result in an underestimate of neutron dose. The present method of using the single n/p value of 1.0 for all locations for 1952–1969 is not supported by quantitative analysis, and may be claimant favorable in many cases. In some cases, however, this value of 1.0 would underestimate the actual neutron dose for some workers, i.e., those working around unmoderated neutron sources. From the information in the current Occupational External Dose TBD, ORAUT-TKBS-0035-6 (Thomas and Szalinski 2007), it is not obvious that the dose reconstructor has sufficient and accurate neutron dose reconstruction information and details available to correctly assign neutron doses for LLNL workers at all locations for the entire time period of 1952 to present.

The Occupational Medical Dose TBD, ORAUT-TKBS-0035-3 TBD (Turner 2005), provides little documentation to support the assumed techniques and protocols applied to calculate the dose, which is mainly derived from Cardarelli et al. 2002. NIOSH believes that when no information is readily available about the energy spectrum, it is reasonable to use the assumptions for DCFs, which are presented in the Implementation Guide (NIOSH 2002) or in ICRP Publication 34 (ICRP 1982).

The Occupational Medical Dose TBD, ORAUT-TKBS-0035-3 (Turner 2005), does consider the potential contribution to dose that may have resulted in less than optimal use of collimation. The generic DCFs have not been verified for use at LLNL. Unresolved is the concern that the DCFs are derived from ICRP (1982) and, therefore, are not comparable in terms of beam quality, which varies from unit to unit. These factors can contribute greatly to the dose to the chest and other organs for units in operation prior to 1985, where little documentation exists.

The Occupational Environmental Dose TBD, ORAUT-TKBS-0035-4 (Thomas 2005), as written, fails to test the adequacy of evaluating the cumulative (additive) effect of numerous source terms at differing locations. SC&A believes that the lack of air monitoring stations within particular areas of known higher releases of a specified isotope does not readily enable one to accurately estimate environmental dose using air-monitoring data from an adjacent air monitoring station. It will be difficult for the dose assessor to accurately estimate environmental dose, without accurate air-monitoring data derived from a station proximal to the release point.

6.1.3 Objective 3: Adequacy of Data

SC&A found that the site profile provided a focused evaluation of the more established and well documented radiation sources at LLNL. In some cases, however, source term definitions are not adequately defined. For example, there is no consideration of potential internal and environmental exposure from thorium and enriched uranium at Site 300. The laboratory was involved in a tremendous diversity of activities at Site 300, the Main laboratory, and at test sites.

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Two major oversights were identified: (1) lack of dose estimation guidance for individuals involved in weapons testing, and (2) inadequate exposure characterization information relating to Site 300. The site profile provides no explanation for how dose reconstructions will be handled in cases where dose reconstruction cannot be done due to lack of exposure and monitoring information, as previously identified by NIOSH in other technical documents.

The Site Description and Occupational Internal Dosimetry TBDs do not give adequate guidance on assessment of all potentially important radionuclides in the source terms. The TBDs identify a large number of radionuclides in the source terms of buildings; however, it does not give guidance on interpretation of bioassay data that have results in gross alpha and gross beta activities, which could be representative of a wide range of the identified radionuclides. Radium and the radon and decay products that would be produced from it are not covered in internal dose guidance in any detail, although it is identified as a major component in the Tank Farm source term and during cleanup of the old air strip. Guidance on assessing intakes of Sr-90 and accelerator gaseous activation products, such as N-13 and O-15, is not provided, although there are indications that these make up significant sources at the site. There is no discussion on the contamination levels (air and surface contamination) that could have been involved with exposures at the site.

There are major issues with verifying the accuracy and usefulness of the data in MAPPER. Bioassay data are not available prior to 1956 for gross alpha and 1957 for gross beta. Tritium bioassay data is only available for 1968 through 1981, and are very limited. There are limited bioassay data in the database for tritium, I-131, thorium, and other radionuclides handled at LLNL, which typically covers only a fraction of the time these radionuclides were handled. Uranium-specific bioassay is not available until 1958.

Sufficient dose data details are not presented in the Occupational External Dose TBD (Thomas and Szalinski 2007) to determine if external radiation personnel monitoring was adequate to monitor beta, gamma, and neutrons before 1958, and neutrons after 1958.

The LLNL Occupational Medical Dose TBD (Turner 2005) is deficient, in that little documentation exists to validate x-ray protocols, equipment maintenance, and upkeep records prior to 1960, which can contribute greatly to the dose to the chest and other organs. There is no other information on such aspects as screens used, grids, film types, and changes in developing parameters. The DCFs are derived from ICRP (1982) and, therefore, are not comparable in terms of beam quality, which varies from unit to unit.

NIOSH has not considered potential sources of data, which provide tritium effluent release data prior to 1972. This includes two significant tritium releases that occurred in 1965 and 1970. Environmental monitoring data for other radionuclides were absent prior to 1961 for the Main Laboratory and 1962 for Site 300, although the Hazards Control Group responsibilities included some environmental monitoring prior to this. The impacts of potential releases from nearby SNLL were not evaluated to determine if they impacted environmental exposures at LLNL. The TBD lacks a methodology to reconstruct environmental exposure prior to 1961.

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6.1.4 Objective 4: Consistency among Site Profiles

The default site profile assumptions and methodologies for LLNL were compared to those of other site profiles reviewed to date. LLNL was primarily involved in the development of the hydrogen bomb, but had numerous R&D activities similar in operations and mission to those at ORNL and LANL. These activities involved using a wide variety of radionuclides. Other site profiles used for comparison included the RFP, the SRS, Hanford, Idaho National Engineering and Environmental Laboratory (INEEL), the NTS, the Mound Plant (Mound), and Portsmouth Gaseous Diffusion Plant (Portsmouth). These comparisons focus on the methodologies and assumptions associated with dose assessments and the derivation of values used to obtain a POC for individual claimants.

Inconsistencies between Site Profiles

The basic default values assigned for determining medical exposure are relatively consistent among site profiles. The site profiles do not apply the latest revision of ORAUT-OTIB-0006 (ORAUT 2005d), which can be corrected in subsequent revisions of TBDs. Other deviations from the standard assumptions are based on site-specific information.

The LLNL Occupational Medical Dose TBD indicates that pre-employment medical x-rays were taken. No routine frequencies for the best estimate, minimizing, and maximizing techniques were identified in the TBD. Dose reconstructors are told to consult the employee's medical records to determine the extent of medical x-rays. The TBD only provides a best-estimate approach, and indicates that it is not feasible to address a maximizing approach. Other site profiles, such as SRS (Scalsky 2005), Portsmouth (Demopoulos 2006), and LANL (Johnson 2004), provide a dose reconstruction approach to maximize the occupational medical exposure. Some site profiles, including Hanford (Shockley and Kathren 2005), SRS, Portsmouth, ORNL (Fleming 2006), and LANL (Johnson 2004), provide detailed technique assumptions, which seem to be limited in the LLNL Occupational Medical Dose TBD. LLNL does not make use of early stack release data to determine potential exposures prior to 1972 for tritium, whereas this was considered in the ORNL environmental site profile (Fleming 2006).

Review of site profiles to date indicates that the NIOSH/ORAU team has not come to a consensus on what components should be considered in the environmental dose. Dose from the resuspension of contaminated soil has not been evaluated in the Occupational Environmental Dose TBD (Thomas 2005). This source of exposure was considered at RFP (McDowell-Boyer and Little 2007), SRS (Scalsky 2005), and NTS (Rollins 2006). Ambient external exposure from contaminated soil was also not considered in the LLNL Occupational Environmental Dose TBD. There is no mention of air immersion exposure from releases of noble gas, which was a part of numerous site profiles, including NTS (Rollins 2006), ORNL (Burns 2004), Hanford, (Napier 2007), INEEL (Bump 2007), LANL (Chen and McDowell-Boyer 2004), and SRS (Scalsky 2005). No attention was given to unique exposures that occurred to LLNL workers at NTS, such as radon exposure in the tunnels (Rollins 2006). In the Environmental Dose TBD (Thomas 2005), NIOSH has reviewed data from air monitoring stations, posted TLDs, and potential inhalation and drinking water intakes from measured concentrations. The TBD provides tables for site-wide annual intakes from inhalation and drinking water. NIOSH has developed

Table 4.7 on site averages for external gamma radiation by year at the LLNL main complex, and Table 4.8 on Site 300 external gamma radiation. In ORAUT-PROC-0060 (ORAUT 2006c), NIOSH has compared maximized ambient dose at various DOE facilities. For LLNL, this maximized estimate is 130 mrem/year, and is applied up to 1984. It then drops down to the 70–85 mrem/year level in subsequent years. These levels are consistent, if not slightly higher, than those at other DOE facilities. However, it is not clear that monitoring stations were positioned in areas of higher releases of specific isotopes proximal to the release point, thus resulting in an underestimation of environmental dose for these higher exposed workers. The analysis considered internal dose from onsite atmospheric radionuclide concentrations and ambient external exposure.

The LLNL Environmental Dose TBD (Thomas 2005) assigns the maximum average annual site-wide values to unmonitored workers based on work location (e.g., Site 300 and the Main Laboratory). When the worker location is unknown, LANL (Chen and McDowell-Boyer 2004), Hanford (Napier 2007), and SRS (Scalsky 2005) assign the site-wide maximum ambient radiation dose. This assignment of a site-wide maximum ambient dose is similar to the LLNL approach. The application of multiple receptor points would be consistent with the approach in the Hanford (Napier 2007), SRS (Scalsky 2005), and INEEL (Rohrig and Bump 2006) TBDs. Although LLNL environmental TBD segregates Site 300 and the Main Laboratory, it has not allowed for multiple receptor points at each of these two locations. The use of measured air concentration data is consistent with the approach applied in numerous other environmental TBDs.

Unlike the LANL Environmental Dose TBD (Chen and McDowell-Boyer 2004), which applied a screening method to the source term to determine relative dose consequences for different radionuclides, the LLNL Environmental Dose TBD (Thomas 2005) does not apply such a screening method. With the similarities in the breadth of radionuclides handled at LLNL, ORNL (Burns 2004), and LANL (Chen and McDowell-Boyer 2004), this screening method, or an equivalent, used at ORNL and LANL is considered prudent at LLNL as well. Overall, SC&A believes that further investigation into environmental source terms is needed.

The basis for assignment of missed internal dose is not clearly defined in the LLNL Internal Dose TBD, nor does the TBD reference applicable TIBs. There have been several TIBs prepared for the assignment of internal dose; however, it is unclear which of them applies to LLNL, because they are not referenced in the TBD. The LLNL Internal Dose TBD has relied on minimum detectable concentrations (MDCs), expressed as the quantity of uranium per liter of urine (micrograms per liter), from LANL, with the assumption that the two laboratories used the same techniques, rather than obtaining these values from only LLNL documentation. The LLNL Internal Dosimetry TBD, like LANL (Argall 2004), SRS Scalsky 2005), Hanford (Bihl 2004), and ORNL (Bollenbacher et al. 2006), has failed to provide guidance for secondary radionuclide exposure.

The LLNL Internal Dose TBD (Berger and Szalinski 2005) does not even mention MTs and, given its publication date, does not refer the dose reconstructor to a specific TIB, such as OTIB-0066 (ORAUT 2007g) or OCAS-TIB-002 (OCAS 2003), which provides a general procedure on how to use IREP to calculate tritium dose from tritides and OBTs. There is no LLNL-specific guidance or general direction on solubility, particle size, or other pertinent internal dose calculation factors. Both the LANL (Argall 2004) and ORNL (Bollenbacher et al. 2006) Internal Dose TBDs discuss solubility classes for their various radionuclide exposures. With the Mound Internal Dosimetry TBD (Millard 2004), there was a more detailed discussion regarding MTs, including appropriate lung clearance classes. The ORNL Internal Dose TBD refers the dose reconstructor to the specific guidance provided in OCAS-TIB-002 (OCAS 2003). The LANL Internal Dosimetry TBD (Argall 2004) also makes some mention of potential exposure to MTs, although it does not go into detail. Given that tritium processes and the special tritium compounds handled at these sites were the same or similar, a consistent methodology is appropriate. The LLNL Internal Dose TBD, published in 2005, lacks the benefit of making reference to the ORAUT-OTIB-0066 (ORAUT 2007g), which provides more recent guidance on calculation of dose from intakes of special tritium compounds.

The LLNL External Dose TBD defaults to a neutron energy of 0.1–2.0 MeV for all facilities with no data supporting this assumption. The ICRP 60 quality factor is highest for this neutron energy group, which is claimant favorable, but inconsistent with other site profiles. The SRS TBD (Scalsky 2005) distinguishes neutron energies and n/p ratios for reactors, fuel fabrication, plutonium production, and radionuclide production and calibration. The INEEL TBD (Rohrig and Bump 2006) considers the reactors, the processing plant, waste handling operations, calibration sources, and uranium handling. Neutron energy spectra and n/p ratios for Pu-238 and Pu-239 operations are segregated at SRS (Scalsky 2005). The categories used in the LLNL TBD lack the detailed analyses seen in these other TBDs. Further evaluation of n/p ratios should include more specific categories, including neutron sources (RaBe, Cf, etc.); accelerators; early subcriticality experiments; and initiator development and neutron spectra from alternate fissile materials. The relative impact of further differentiation of n/p ratios will depend on the particular neutron source.

The LLNL External Dose TBD indirectly addresses non-penetrating exposure to workers by referring them to the guidance in ORAUT-OTIB-0017 (ORAUT 2005a). Other site profiles are still in the process of including guidance on non-penetrating exposures. The Pantex (Fix et al. 2006) and RFP (Langsted 2007) External Dose TBDs briefly mention extremity exposure and how to assign dose. The LLNL External Dose TBD does not mention potential extremity exposure, which was significant in core handling. This is also a shortcoming with many of the other site profiles.

The Y-12 TBD (Kerr 2006), the SRS TBD (Scalsky 2005), and the Hanford TBD (Scalsky 2007) base their default exposure geometry on the compensability or non-compensability of the claim. The Mallinckrodt Chemical Worker (MCW) (Westbrook and Bloom 2007) and RFP (Langstead 2007) TBDs based default exposure geometries on job titles. The LLNL TBD (Thomas and Szalinski 2007), the LANL TBD (Widner 2005), and the INEEL TBD (Bump 2007) choose to default to 100% Anterior-Posterior (AP) exposure. Further evaluation of exposure geometry for photon and neutron exposure should be evaluated for LLNL workers to determine if 100% AP geometry is appropriate for all LLNL workers. The NIOSH/ORAU team should consider development of a consistent default assumption for exposure geometry in all site profiles.

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In general, the Integrated RadioEpidemiology Program (IREP) input criteria for Radiation Rate, Radiation Type, and Dose Distribution Type are the same for LLNL as for other site profiles. External dose assumptions were consistent with those used in other site profiles. The default energies for beta, photon, and neutron exposure were >15 keV, 30–250 keV, and 0.1–2.0 MeV, respectively. The missed external dose is calculated using the MDL/2 calculation times the number of monitoring periods, and is entered as a lognormal distribution with a GSD of 1.52.

6.1.5 Objective 5: Regulatory Compliance

SC&A reviewed the site profile with respect to Objective 5, which requires SC&A to evaluate the degree to which the site profile complies with stated policy and directives contained in 42 CFR Part 82. In addition, SC&A evaluated the TBDs for adherence to general quality assurance policies and procedures utilized for the performance of dose reconstructions. The hierarchy of data used in the dose reconstruction process begins with the use of individual monitoring data as a priority. This is fundamental to the performance of dose reconstruction. NIOSH has complied with the hierarchy of data required under 42 CFR Part 82 and its implementation guides. As mentioned above, quality assurance with respect to claimant-specific information is lacking, such as the verification of electronic data, with hardcopy results or the completeness of data provided by the site for dose reconstruction. LLNL staff has raised concerns regarding the use of MAPPER for coworker modeling, stating various issues with the database. With DOE facilities concerned with classified projects, a review of classified documents is required to ensure that information relevant to dose reconstruction, including personnel or environmental monitoring data, are not being missed.

6.2 USABILITY OF SITE PROFILE FOR INTENDED PURPOSES

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

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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.

6.2.1 Ambiguous Dose Reconstruction Direction

Our review has identified that clear and unambiguous direction on internal dose reconstruction has not been provided. Supportive background information/data and specific instructions should be presented in a logical manner that ensures understanding, process efficiency, and consistency among dose reconstructors. The Occupational Internal Dosimetry TBD (Berger and Szalinski 2005) identifies a large number of radionuclides in the source terms of buildings and their activity fractions; however, it does not give guidance on interpretation of bioassay. The site profile provides no explanation for how dose reconstructions are completed in cases where dose reconstruction cannot be done, as previously identified by NIOSH in other technical documents for weapons testing sites.

The LLNL Occupational External Dose TBD (Thomas and Szalinski 2007) is seriously lacking in details on external doses during the years 1952 to the present, and many LLNL site-specific documents are lacking. It relies extensively on other generic documents applicable to the DOE-wide complex, and does not develop the data and issues specially related to the conditions at the LLNL, Site 300, and other locations where LLNL workers were exposed. The in-depth development of important areas necessary to evaluate the adequacy of monitoring, dosimetry response, dose records, and other related issues are not available in the present TBD; this is especially true for neutron radiation. This lack of detail is inconsistent with other site profile external dose TBDs. The present LLNL Occupational External Dose TBD would require extensive revision to meet the needs of dose reconstruction.

6.2.2 Inconsistencies and Editorial Errors in the Site Profiles

Table A-1 in Attachment A of the Occupational Internal Dose TBD (Berger and Szalinski 2005) has different radionuclides listed for Buildings 132 and 151 than those presented in Table 5-1 for these buildings. Table A-1 in Attachment A shows Building 151 with plutonium isotopes making up the majority of the activity in the building, while Table 5-1 in the text of the Occupational Internal Dose TBD shows only one plutonium isotope (Pu-236) in the building at a very low fraction of the total radionuclide activity. There does not appear to be a good reason to have both of these very similar tables, and it is close to being redundant with the risk of disagreement, as found in this review. It may be less confusing to just show one table in the TBD.

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6.3 UNRESOLVED POLICY OR GENERIC TECHNICAL ISSUES

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

(1) Direction on the applicability of other site TBDs and/or TIBs to individual dose reconstructions is absent. The TBDs need to be revised to reference new TIBs, and make certain that all guidance is cohesive and not conflicting.

(2) Mobility of work force between different areas of the site should be addressed. Site expert testimony that many workers moved from one facility to the next within the same DOE facility is a complicating factor. Establishment of an accurate worker history is crucial in such cases. This will be especially difficult for family member claimants. NIOSH/ORAUT has developed ORAUT-OTIB-0052, *Parameters to Consider When Processing Claims for Construction Workers* (ORAUT 2007a), which specifically addresses construction workers.

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

(4) Dose from impurities and/or daughter products in radioactive material received and processed at sites should be assessed as a contributory exposure source when not taken into account using the standard internal and external dosimetry methods.

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

(6) 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.

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

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(8) 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.

(9) Dose reconstruction for workers involved in nuclear weapons testing, and radiological work at other DOE facilities as a LLNL employee, are often not possible due to lack of exposure data during these activities.

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

(11) Verification of the completeness and accuracy of databases used in coworker models should be evaluated prior to use.

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ATTACHMENT 1: NIOSH TECHNICAL DOCUMENTS CONSIDERED DURING THE REVIEW PROCESS

Technical Basis Documents

ORAUT-TKBS-0035-1, *Lawrence Livermore National Laboratory l – Introduction, Rev. 00 PC-1* (Maisler 2005a) September 12, 2005.

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ATTACHMENT 2: SITE EXPERT INTERVIEW SUMMARY

Interviews were conducted with seven former Lawrence Livermore National Laboratory (LLNL) personnel as an initial evaluation. The purpose of these interviews was to receive first-hand accounts of past radiological control and personnel monitoring practices at LLNL. Interviewees were selected in coordination with the EEOICPA site coordinator and Tri-Valley Cares (a public advocacy group), based on guidance provided by SC&A/Saliant. The interviews were conducted by Joseph Fitzgerald (Saliant), Kathryn Robertson-DeMers (Saliant), and William James (Saliant) from April 14–19, 2007. At the request of the LLNL EEOICPA coordinator, SC&A limited the onsite visit to classified and unclassified records review with the intention of following up with current worker interviews at a later date. Face-to-face interviews were conducted with retirees in Livermore, California. Further input was provided to written questions by various current maintenance, engineering, and security staff in June 2007. Questions were submitted to LLNL internal dosimetry staff; however, responses have not been received to date. Personnel represent experience at the site ranging from 1958 to the present. Workers were briefed on the purpose of the interviews, and background on the EEOICPA dose reconstruction program and site profiles, and asked to provide their names in case there were follow-up questions. Participants were reminded that participation was strictly voluntary and that all interviewer notes would be reviewed for classification following the interview.

Former workers represented operations in Buildings 111, 123, 131, 231, 261, 271, 331, and 332. Other operations represented included Site 300 and weapons testing at the NTS, the PPG, Amchitka (Cannikan), and a number of Plowshare events. Also included were support personnel who worked throughout the site. The job categories or groups included the following:

- Corporate Environmental Safety & Health Management
- Dosimetry
- Hazards Control Management/Team Leads
- Health Physicist
- Health and Safety Technicians
- Machinist
- Maintenance
- Security
- Staff Scientist
- Technical Supervisor
- Theoretical/Experimental Physicist
- Tri-Valley Cares

The information site experts provided to SC&A/Saliant has been invaluable in helping us understand the diverse activities conducted at LLNL. This is not a verbatim discussion, but is a summary of information from multiple interviews. The information provided by the interviewees was based entirely on their personal experience at LLNL and the testing sites. It is recognized that site expert and former LLNL workers' recollections and statements may need to be further substantiated; however, they stand as critical operational feedback and reality reference checks. This interview summary is provided in that context. LLNL site expert input is similarly reflected in our discussion. With the preceding qualifications in mind, this summary has contributed to issues raised in the site profile review.

General LLNL Information

Numerous divisions were involved in the development and testing of devices and weapons. One site expert described the distinction between a device and a weapon:

> *A nuclear device is basically a "physics experiment." It is intended to verify some type of physics principal* [sic]. *These experiments are usually "new" ideas and many are not successful. Nuclear devices are typically a one of a kind, often handcrafted types of nuclear assembly's* [sic]. *On the other hand, a nuclear weapon is a successful device test* [sic] *that has been assigned a specific military purpose. This could be the warhead for a Polaris missile, an air force bomb or an army artillery shell. A weapon must fit within the constrained physical envelope of its specific delivery system. It must also meet the stringent "shake, bake, rattle and roll" storage, transport and delivery environment. It must be highly reliable over a long stockpile life. Most weapons systems incorporate sophisticated safety and security systems into their operational envelopes. Weapons also have to incorporate designs compatible with large numbers of production units.*

The Physics Division was responsible for conducting weapons modeling via computer and proposed new methods to be tested. B-Division was responsible for development of primary systems. A-Division concentrated on development of secondary systems. L-Division designed the diagnostics for tests. The Device Division provided the engineering technology for experimental and prototypical nuclear weapons systems.

The LINAC was operated from Monday-Friday and shut down on Friday night for the weekend. This allowed targets to cool prior to handling. Monday was established as the maintenance day for the accelerator. Technicians were required to survey the length of the accelerator prior to entry, and they also provided job coverage. Bremstrahlung and activation products from the accelerator components were the primary source of exposure during shutdown status. The facility had an interlocked fence, as well as interlocked access to the drift tube area. The facility had a concrete roof. Most of the technicians' dose came from the 100 MeV LINAC.

LLNL operated reactors, subcritical assemblies, and critical assemblies at Livermore and NTS. The Subcritical Test Facility (Building 261) was used by N-division to conduct various tests. The Kukla Prompt Burst Reactor was built and tested at this facility.

The primary reactor at the Livermore site was the Livermore Pool-Type Reactor (LPTR), which operated from 1958 to 1980. A central regulatory rod was mechanically operated through an attached gear. Four of the control rods were held by magnets, which could be easily dropped to scram the reactor. The reactor core was in a tank with 26 feet of water. Cooling water cycled through the reactor at a rate of approximately 1,000 gallons per minute. The reactor was operated from Monday through Friday and was shut down over the weekend. On Monday

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morning, the 3-foot long fuel elements were rotated and unused fuel was stored in storage racks along the edge of the reactor vessel. Rotation was necessary to obtain an even burn on each of the fuel elements. The fuel was replaced when it no longer produced more neutrons than it absorbed. A 7,000 lb coffin was lowered into the reactor pool and the used fuel was loaded with a crane into the coffin under water. The shipping container was capped and removed. It was allowed to cool for 5–6 months prior to shipment offsite for storage.

There were several beam ports at the reactor used to irradiate various types of targets. A pneumatic tube system was also available to shoot targets within containers (called rabbits) into the core for irradiation. Several irradiation positions were available in the reactor pool for irradiation of targets. These targets were sealed in an aluminum container and lowered into the reactor while it was shutdown. An aluminum wire was tied to the end of a string to help guide the targets into position. Irradiation time varied by experiment, but ranged from seconds to months. Most of the experiments conducted were physics experiments. Reactor operators were responsible for loading and unloading targets. Unloading of targets was done with long tools to increase the distance between the operator and the target. Hazards Control was present when targets were removed from the reactor. Targets were allowed to cool for at least 30 minutes prior to removal. Operators were also allowed to do radiation monitoring when a technician was not available. Prior to LPTR, there was a spherical tube of water with a graphite reflector. Uranium was put into the tank to conduct subcritical tests. It was shut down around 1959.

The Research and Development (R&D) activities at LLNL were diverse and involved a number of facilities. Although much of the AVLIS-related work involved uranium, there was some research done at the Plutonium Facility (B-332) with plutonium. Project Sherwood was associated with fusion research conducted at the laboratory. The primary radiological hazard associated with this was the x-rays produced by the rectifiers. There were also nonexplosive tests conducted on nuclear components, such as the Swordfish Project (studying the effects of seawater on nuclear components). Environmental chambers were available to study the effects of environmental conditions (e.g., heat, humidity) on components at Site 300. Some plutonium was handled during these tests.

Research and Development (R&D) was included in the activities that occurred in the Engineering Building (Building 131). A high bay was used for shot preparation (e.g., electrical tests). There was weapons-related vault storage in this building primarily containing depleted uranium. The main material storage vault was located in Building 231. Nuclear Chemistry shot diagnostic activities occurred in Buildings 151 and 251. Smaller quantities of thorium were handled in Buildings 151, 222, and 241. The old Radiochemistry Building (B-222) may have conducted limited R&D involving fluorination of small quantities fissile material. There were no measurable amounts of neutrons in this area.

Chemists did not operate in the safest manner, even though there were safety procedures for the jobs they conducted. For example, on occasion, they stored radioactive materials in file cabinets. Radionuclides were carried back and forth between the laboratory and separations areas.

One of many operations in the Plutonium Facility involved plutonium that was shipped from other DOE complex sites to LLNL for "clean-up" or purification. There were some glove bag ruptures, window cracks, and cuts in gloves; however, there were not a lot of accidental intakes. Hazards Control did not put up with sloppy work practices, and plutonium was not often handled in liquid form. No plutonium buttons were produced at LLNL. Pits for testing came from RFP and other materials came from SRS and Hanford.

The Heavy Elements Facility (Building 251) was involved in the evaluation of radionuclides to determine fission cross-sections. These elements were used for diagnostics testing. Challenging health physics issues arose in this and the core processing area, often with high dose rates involved. Much of the work was done in manipulator boxes, because of the high specific activity of the radionuclides. LLNL developed AERIN, which was an internal dosimetry model used for heavy elements.

The Biomedical Sciences Group in the 360 area of the laboratory was involved in cancer research, where animals were injected with radioactive solutions.

LLNL has been involved in the decontamination and decommissioning (D&D) of several older facilities over the last 10–15 years. A Space Action Team (SAT) was assigned to D&D operations to perform comprehensive assessments of past events in obsolete buildings (e.g., 222, 170 series buildings) designated for demolition. Other facilities are in the decontamination phase and the inventory of radioactive material has been reduced (e.g. Building. 251, the heavy elements facility). In the early years of the laboratory's operation, the taxi strip of the former naval air station was used for storage of liquid waste. The goal was to evaporate the liquid waste in open vats and reduce it to a near solid form. Plastic- and concrete-lined trays for evaporation of low-level liquid waste leaked and penetrated several feet into the ground at the old taxi strip. This area was remediated (excavated) in the early 1980s to eliminate the contamination. Radium was identified during aerial surveys of the site in areas where the military buried radium dials when they had ownership of the site.

LLNL was working in collaboration with Mound on tritium cleanup efforts. These processes involved tritides. Much of the tritium research work was discontinued with the end of the cold war. Tritides were used in accelerator target material. They did not pose much of a hazard in this application. The targets were removed with the use of remote tools. The plates were disassembled and weighed. There was a significant need for shielding during this operation.

LLNL was responsible for the Plowshare Program. Events from the Plowshare program included Sedan, Cabriolet, Buggy (5 simultaneous detonations), Gasbuggy, and Rulisen. L- and R-Divisions were responsible for the Treaty Verification activities. Studies were conducted to gain important information on how to identify production and testing of nuclear weapons by other countries. For example, the Plowshare shots conducted in Mississippi were done in a salt dome. Salt domes in Russian are used by Russians to conduct their weapons tests. Measurement studies above ground were completed to ensure that equipment used was sensitive enough to detect activity in a salt dome.

LLNL was involved in a number of international activities, which involved potential exposure to radiation. LLNL employees wore their laboratory dosimeters and, in some cases, secondary dosimetry (e.g., pencil dosimeters).

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Security

The security services at LLNL were under the jurisdiction of the DOE site contractor, the University of California. Materials Management was responsible for verifying incoming and outgoing shipments of weapons, weapons components, and Special Nuclear Material (SNM). DOE couriers were responsible for transportation of shipments between DOE sites. Protective Service Officers (PSOs) were responsible for accompanying shipments to other areas of the Livermore site (onsite shipments). The percentage of time spent on these activities was dependent upon the particular job assignment.

Materials were stored in both the production areas and in vaults across the site. Material Vault Areas (MVAs) and Material Accountability Areas (MAA) had Twp-Person Security Systems (TPSSs) in placed that were used during certain operations. The buddy system was used in the Category I facilities (i.e., B-231, B-239, B-261, B-332) for security and/or safety reasons (e.g., machining operations, explosive tests). This was particularly the case during SNM movement. PSOs were required to guard single or multiple SNM components when other protections were not available. The details of material types were not always disclosed to guards. Time spent on this duty ranged from rarely to several weeks in a row. Sometimes there was a wall between the guard and the SNM, while at other times, there was not (e.g., Site 300, transportation down the hall).

Security occasionally provided escorts for offsite visitors and others, which involved entry into radiological areas. This was done in situations when uncleared individuals were allowed to enter sensitive facilities (e.g., B-332). LLNL guards were loaned to other DOE facilities after about 1980. They also provided additional security support to offsite college campuses as necessary to control riots.

In the early 1980s, a lot of facilities worked with SNM, whereas currently, it is more limited. There was a large inventory onsite handled in multiple places. In 1985, the SNM was consolidated in one location. After 1985, security became involved in training for security threats. Some of these exercises took place onsite (e.g., around the B-332 yard area), while others occurred at other DOE facilities (e.g., Hanford in 1984). Staff members interviewed were not involved in security work at nuclear testing sites.

Security was the first on the scene at incidents and accidents. The responsibility of security during incident response was to control traffic and access to the area, and maintain the integrity of the area. Security reports were filed when incidents occurred. At one time, these records were stored at B-141, then at B-832E. The current location of these records is unknown. A few site experts indicated they were involved in a number of incidents over the course of their employment at LLNL.

Entry and security logs were used at some locations. They were originally stored at the post or at B-271. Many of these logs were transferred to the records archive. There were areas with security or entry logs. At one time, all records were stored at B-141, then at B-832E. Muster logs were located in the B-231 and B-332 vaults. Security had some involvement in disposal of classified records at the Hammermill Facility. The records were collected and sent to

Hammermill for pulverization with a hammer. Although they were involved in the disposal, security did not know the contents of the records.

Guards were routinely assigned dosimetry for measurement of external exposure. Several security site experts indicated that they did not receive any measured external exposure, but if an individual was involved in a mishap, they could receive some exposure. There were some duty stations that resulted in more radiation exposure than others (i.e., B-332). There was no particular subgroup of security staff who routinely received more exposure than others. Many of the security personnel interviewed do not recall having to submit bioassay samples (urine or fecal). A majority of them indicated they did not receive lung or WBCs. The PPE worn in areas such as B-332 were standardized for all workers. Some security staff indicated that there were situations at the laboratory where PPE was not the same for two workers in the same vicinity. PPE used in areas where SNM was stored included lab coats and shoe covers for B-332, and yellow booties at the firing tables at Site 300.

Maintenance and Crafts

Coordinators were responsible for different maintenance activities (e.g., lighting, air conditioning, heating, etc.). For a particular area of expertise, such as heating and air conditioning, an individual could be sent anywhere onsite where this service was needed. There were some individuals who were assigned to a particular building.

Maintenance operations involving hands-on work with radioactive material or contamination included machining, casting, chemical analysis, waste handling (turning waste back into oxides), glovebox work, welding and welding setup, and electron beam cleaning. The machining, milling, and cutting of uranium for test shots were completed in the B-321 NC Shop (U-235) and B-332. Chip fires occurred on occasion in both of these areas. Beryllium was handled in the immediate vicinity of uranium and/or plutonium in both B-321 and B-332. Back at the peak production era, there were fairly constant operations and other metal processing in these areas. During these operations, High Efficiency Particulate Air (HEPA)-filtered local ventilation enclosures were used. There was also some thorium machining done in this area. Radiography and/or x-ray sources were used to verify the integrity of welds and in orientation of assemblies. Operations were associated with B-239.

Site 300

Site 300 is a remote area removed from the main LLNL site and populated areas. Offsite residential developments are currently expanding toward that location though. Preliminary weapons component testing was conducted, including explosive testing of small-scale devices and machining of explosives. The Device Division conducted hydrodynamic shots (hydroshots) at Site 300 and hydro or subcritical tests at NTS. The shots were used to test devices and associated diagnostics. There were as many as 15–20 hydroshots in preparation for a device or weapons test at NTS, the PPG, or other test sites. This number decreased over time as the lab became more efficient. These hydroshots were detonated on open air shot tables. During the actual detonation, workers were inside a concrete bunker 15–20 feet below ground. Large quantities of heavy metals were used in hydroshots. A single shot could contain hundreds of pounds. A large quantity of depleted uranium (DU, D-38) was used in the hydroshots. The

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health physics hazards associated with this operation included exposure to radioactive material from open table shots, flash x-ray, and real-time radiography. The flash x-ray and radiography instruments were interlocked, shielded, and controlled for the workers' protection.

Diagnostics had to be carefully installed and manually set in place. This required staff to lie in the dirt to make sure placement was precise. The bunkers had port holes, where cameras are placed to film the test. Scientists could observe the test and track its progress. These tests were documented in reports that described the results. Minimal protective clothing was worn during preparation work at Site 300 in the early years of operation.

Among other tests conducted at Site 300 were dynamic gas flow studies. Extensive documentation exists describing these experiments. These studies were conducted to certify theoretical calculations developed at the laboratory.

Radioactive materials used in the shots included uranium, tritium (e.g., tritides), and thorium. Many of the shots used depleted uranium; however, thorium was used fairly consistently. The source of the thorium was Y-12 or LLNL itself. Post-shot re-entry occurred within approximately 30 minutes of the hydroshots to evaluate what material was left and to recover diagnostics. The device being tested was usually pulverized by the explosion. Sometimes PPE was used, while at other times it was not. These re-entries resulted in a potential for exposure. The W-Division also conducted non-nuclear explosive tests (e.g., skid tests). Thorium and uranium were handled by workers wearing latex or cotton gloves. Gloves were used primarily to prevent moisture from damaging parts. Booties were required to enter the gravel firing table area after shots. Once the gravel reached a specified level of uranium or beryllium activity, it was replaced.

The nature of the hydroshots dispersed D-38 to the area around the firing table. Some D-38 shrapnel was dispersed from the hydroshots. Environmental radiological contamination has been found around the shot tables. Beryllium contamination was also an issue. There are also waste burial and handling sites located here. It was used as a burial site in the 1960s and 1970s, where animal carcasses from the laboratory's biomedical program were buried. Studies were conducted of contamination in this area. Site 300 is now considered a Superfund site. There is soil and groundwater contamination associated with this area. There was little historic concern with contamination until concern arose regarding offsite environmental releases. The surrounding community population is expanding out to the Tracy area where Site 300 is located.

Weapons Testing Activities

There were several organizations involved in testing at NTS, including the Defense Nuclear Agency (DNA), LLNL, LANL, SNL, REECo (the site contractor), and other supporting subcontractors. For LLNL, the device was constructed as a design model at LLNL. Component parts for nuclear tests were manufactured at the AEC integrated contractor facilities, including the RFP, Y-12, the Bendix Kansas City Plant, American Car and Foundry, Pantex, and in LLNL's own shops on the main site and at Site 300. These components were shipped to NTS Building 10, where final assembly, component modifications, interface inspections, and portable radiographic checks were made. There was sanding and filing of parts conducted in the

Assembly Bay to make components fit better. The design of the diagnostics canister was done by LLNL and assembled at the site by contractors, such as Edgerton, Germeshausen and Grier (EG&G) in Las Vegas. EG&G was responsible for fabricating the diagnostic equipment used in testing. Some of the final assembly work had to be coordinated with other laboratories. Equipment and components were placed in massive canisters and transported to NTS. Transportation of support personnel (e.g., engineers, scientists) to and from NTS was initially provided by a two-engine D-18. In 1963, as the work at NTS increased, a DC-3 (referred to as "Amy") was added to the fleet. LLNL staff was responsible for evaluating the posted test data and technical aspects of the event.

DNA conducted tests with weapons of known design. Tunnels were dug in the portions of Rainer Mesa facing Yucca Flats to support DNA operations. Yucca Flats was designed for lower-yield devices, and the backside of Rainier Mesa (northern portion) was designed for higher-yield devices. Rainer Mesa, Area 12, and Area 16 were used for DNA research (tunnel and transient radiation effects). Through contract with DNA, LLNL provided support in trying to understand tunnel events. This involved development of codes and conducting high-explosive gas shock and air jet experiments. They oversaw events conducted by DNA at NTS.

Weapons tests at NTS, PPG, and other test sites involved approximately 100 personnel (e.g., assemblers, diagnostics, electronics, logistics, chemistry, engineers, scientists, and Hazards Control). Tunnel shots took longer to prepare for, and involved from 400–500 LLNL personnel. The Nuclear Test Engineering Division (NTED) was responsible for all mechanical, civil, structural, diagnostic, and containment aspects of underground nuclear tests. It was also responsible for the test site field operations, including the arming, detonation, gas systems, diagnostics, emplacement, and containment of nuclear tests. The Nuclear Test Electronics Engineering (NTEE) provided electronics support for the tests. These personnel were also involved in assembly and re-entry support post-testing. Laboratory personnel could be stationed at the test site for weeks, depending on their job responsibilities and the particular tests conducted.

Full atmospheric tests of systems took place at NTS and PPG. A majority of these nuclear tests occurred at NTS at Frenchman Flats and Yucca Flats. During the late 1950s and early 1960s, over 100 atmospheric tests were done, for which there was no containment effort. Atmospheric tests focused on evaluating new weapon designs.

LLNL Experimental Device assembly work was done in special secured facilities. During certain phases of the assembly process, dosimetry badges would be removed for explosive safety or as a damage precaution when handling certain materials. Nuclear devices contained exotic radioactive materials, high explosives, plastics and plasticizers, bonding agents, and solvents of all sorts. Weapons engineers were exposed to these materials. Employees were sometimes cavalier about handling chemicals and radiation. Once that phase of the assembly was completed, badges would be put back on. The assembled nuclear device or weapon was transported to the "forward area," Frenchman or Yucca Flats, where it was placed on a tower or anchored to a balloon for detonation.

The shots were fired from the Control Point (CP), where test support staff was located. The CP overlooked the Yucca Flats, where pre-shot evaluations and the tests were done. Containment physicists would review the design of the containment with the site director. Early morning briefings occurred to discuss the stability of the weather and whether the shot could proceed. The shot was not performed during bad weather. The site manager would give the okay to detonate the device. Observations of the actual detonation were made from the Central Control Point (CP1). Most of the time, darkened glasses were provided, but on occasion, personnel were directed to "turn away."

Re-entry teams for special effects shots recovered items that had direct radiation exposure from weapons. Teams took turns doing portions of the recovery, with Hazards Control technicians accompanying them. Post-detonation, Hazards Control personnel would enter the area to determine whether radiation leakage had occurred. When the "all clear" was given, scientists went into the area to retrieve the diagnostic equipment and information recorded by the remote system in the trailer for atmospheric tests. No PPE was worn into the area for this operation after it had been cleared. Re-entries were conducted within hours after a detonation at NTS. Time restrictions were applied by Hazards Control. For tunnel shots, anti-contamination clothing and respirators were used. Re-entries resulted in the largest doses during the weapon tests.

During atmospheric testing just prior to the Test Ban Treaty of 1963, there were a lot of "shots" in a relatively short period of time. Personnel worked long hours at the test sites. According to the site expert, the priority was to get the "shots" done on schedule, and sometimes "the rules" got compromised. During atmospheric testing, scientists from the Nuclear Chemistry Division flew through clouds immediately after the weapons detonation to collect gas samples. Upon entry into the "underground" era of testing, more standard operational procedures were developed.

Underground tests required that a hole be drilled into the ground for insertion of the device. The weapon was placed down the main hole and the hole was backfilled to the surface. It is important to note that different tests may be performed in the same geographical areas. That meant holes for new tests could be drilled very close to ground zero (GZ) from previous tests. The area around GZ was vaporized and melted rock was found at farther distances away. For example, a 1-megaton shot vaporized rock up to 20 meters in radius, and melted rock as far away as 40 meters in radius.

During the initial years of underground testing, many new and difficult challenges arose. Underground test holes and caverns, large and deep enough to contain the energy release by a nuclear explosion, proved difficult and costly. Containing the nuclear blast and its radioactive byproducts underground required new "containment" science and field technology. The capture and analysis of nuclear diagnostics systems data via "hardened" detection/electronics, and thence through miles of coaxial cables, was a daunting requirement. Shock mitigation of relatively delicate electronics was particularly challenging. New environmental "canisters" for the nuclear devices, diagnostics, containment, and cable systems were all new technology. New computer codes had to be developed for the test itself. The canister was installed by lowering it into the circular hole drilled into the ground. Different layers of backfill (different materials) were added. Attached to the canisters were the diagnostic cables used to record performance of the

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device. These diagnostic cables came up through the ground and went to trailers an adequate distance from GZ. Recording was conducted without the presence of employees in the trailers. When the subsidence crater occurred, the cables could be pulled away from the trailers. The list of challenges went on and on.

One site expert explained:

> *Nuclear test technology evolved rapidly in the late 1960s. Shot yields got larger, diagnostics became very sophisticated, turnaround times became shorter and safety improved.*

After underground tests were completed, the LLNL Nevada Group arranged for core sampling. After the weapon was detonated, gases from the explosion cooled and the overburden collapsed, creating a crater. The ground had to be stable prior to re-entry, and the area had to be cleared for health purposes. REECo was responsible for drilling the holes and digging tunnels. Drillbacks occurred within 2–5 days of the underground tests. A sample was extracted from the detonation site. This sample was taken to a trailer or the "Blue Building" at NTS. With tongs, the sample was segregated to identify pieces with high-level activity (referred to as high-grading). The segregated portion was placed into a bag or a vial, then into a steel capsule (1–2 R/hr at the capsule). The steel capsule was put into a lead pig and flown to LLNL for analysis. The core sample was brought from the airport to Building 151 (Building 103 prior to its existence), where it was put into a glovebox and divided into sub-samples for the various analyses to be conducted. Air filters collected during atmospheric weapons testing were analyzed by wet chemistry and counted in Building 101. Air filter samples, regardless of the sponsor, were split between LLNL and LANL. Hazards Control provided coverage during the transportation and handling of core samples and air filters.

When LLNL personnel worked at the NTS, they generally stayed onsite. If they worked "events" that were located on the Frenchman and Yucca Flats area, they usually went back to Camp Mercury. However, because the days were so long and the travel distances so far when they worked events located in Area 12 (the tunnels) and/or on Pahute Mesa, they stayed at the Area 12 Camp or on the Mesa itself. The Area 12 Camp was a scaled-down version of Camp Mercury. Very often, even events on the Yucca Flats had schedules that required personnel to stay nearby. There were many work trailers that been minimally outfitted with a few beds, a refrigerator, and a hotplate. Dosimetry badges were typically removed during recreation and at Area 12 or Camp Mercury, where personnel slept and ate.

According to site experts, life on the tropical Christmas Island was much more "casual" than at the NTS. Hence, the people on the island had fewer security issues and more recreational time. This resulted in much more casual dress (usually shorts and sandals), and less concern about constant dosimetry badge-wearing.

Events

Operation Dominic was the largest U.S. nuclear test operation ever conducted. The device assembly work for tests in the Pacific was done at Barbers Point Naval Air Station in Hawaii.

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They were flown to the drop areas by B-52 bombers. Thirty-six atmospheric tests were completed at the PPG between April and November 1962. About 500 people from LLNL were involved. Most of the tests were airbursts, with the devices dropped by B-52 bombers. The typical test in this series was a high-yield thermonuclear test that was observed from Christmas Island. Christmas Island atmospheric tests were evaluated by electronic detectors and physical particle samples. Both of these methods were conducted airborne and on the ground. As a result of weather anomalies or "off target" detonations, there was "fallout" from tests that ended up "dusting" the island. LLNL personnel also participated in Operation Nougat, which ran from September 1961 to June 1962. Operations Dominic and Nougat were the last atmospheric tests conducted prior to the Limited Test Ban Treaty.

LLNL was responsible for the Cannikin 5-megaton experiment conducted on November 6, 1971, in Amchitka, Alaska. The preparation took nearly 5 years. The weapon was placed in a 90-inch diameter hole that was drilled over 6,000 feet deep. At the bottom of this hole was a mined cavity over 50 feet in diameter. Four hundred tons of "hardware and electronics" cabling was lowered into the hole with the weapon. The "shock mounted" diagnostic recording trailers were located 2,000 feet from GZ. The blast generated a ground motion of 7.0 on the Richter scale. The corresponding peak ground displacement of over 15 feet was measured at the diagnostics trailer. All experimental data were recovered for this shot.

Other Activities at NTS

In addition to hydroshots at Site 300, LLNL conducted subcritical and high-explosive tests at NTS (Area 16). Mock-up devices and weapons with the primary were used in these tests. Subcritical shots at the NTS had all the elements of a full-scale nuclear test, but the nuclear materials were "diluted," so they would not go critical. The majority of the diagnostics were electronic detectors. These tests were typically underground tests, where devices were placed about 150 feet below ground. Some of the subcritical shots were aboveground, such as the Vortex Project. During the test moratorium, all tests at NTS were subcritical tests. During the execution of "subcritical" tests, it was necessary to work "upside down" in relatively tight, underground quarters. All personal materials, including badges, had to be removed for assembly safety. High-explosives testing were conducted for R&D.

Several one-point safety shots (e.g., test of only the primary) were conducted for almost every weapon at NTS. Project 56, which involved plutonium, started in Area 11 at NTS in 1955. Four safety shots were conducted, with the first three occurring without issue. The fourth shot did not go as planned. There were higher than expected external exposures. The Roller Coaster Event, conducted in the 1950s, also involved plutonium shots.

LLNL ran the Tweezer Facility located at NTS. This facility was used to conduct tests on pits. For example, personnel were required to stay at a predetermined safe distance from hot dry runs and other runs. Other LLNL activities that occurred at NTS included the Pluto Project, the development and testing of the FRAN prompt burst reactor, and the development and testing of the Super Kukla reactor. The Pluto Project involved the development of a reactor core built at LLNL and tested at NTS. Beryllium was used as a reflector. This was related to a sub-atmospheric suborbital mission. N-Division was involved in all three of these projects.

Tunnels used for the Spent Fuel Climax Project (SFCP) were left over from the Piledriver experiment. During this project, they excavated a large area of tunnels in the granite rock. Tunnels that went back to the area where the explosives were set off were closed up. The elevator is located at the top of the surface where the excavated material was hauled out. They added a large room, which was used as an assembly area. The elevator was also used to carry materials down to this room. This room should not have been affected by the explosions. For the SFCP, gauges and other equipment had to be installed in the wall near the spent fuel sites. Spent fuel rods from a reactor were loaded into storage areas underground in the room. Diagnostics to analyze the effects on the granite were placed in the rock in the immediate area. Operations were done remotely. A report was issued on the setup of the SFCP. This work lasted approximately 5–10 years.

General Radiological Control

Radiation protection, industrial hygiene, industrial safety, criticality safety, and environmental monitoring were originally part of the Hazards Control Division. Technicians and supervisors worked for teams. Exempt staff was initially in a central organization. Most professionals were eventually moved out to the field to get them more involved in the resolution of team-specific issues. LLNL assigned the right people to the right areas, depending on their expertise. Individuals were not matrixed to operations, but always took their direction from the Hazards Control Division.

Professionals, supervisors, and technicians were responsible for implementing all disciplines of safety. Health and safety technicians covered multiple safety disciplines. They were responsible for conducting health physics monitoring and planning, industrial hygiene monitoring and planning, and identification and control of industrial safety hazards. They were also assigned duties associated with critical safety and some environmental monitoring tasks. Technicians had a primary focus, but were required to support the other safety disciplines.

In the 1960s and 1970s, the Radiation Safety Section of the Hazards Control Department consisted of approximately 22–27 staff members, including Operational Health Physics, Operational Health Physics (HP) Technicians, External Dosimetry Professionals, External Dosimetry Technicians, Internal Dosimetry Professionals, Internal Dosimetry Technicians, Counting Room Professionals, Counting Room Technicians, and Radiation Calibration and Repair Technicians.

Operational HPs supported a particular Safety Team that was established to support various programmatic areas (e.g. the Plutonium Facility, Hazardous Waste Management, Biomedical Program, Physics (accelerators), Chemistry, etc.). In addition to those above, there were 20–30 health and safety technicians who supported all safety disciplines (radiation safety, industrial hygiene, industrial safety, fire safety, and explosive safety). Much of the technical staff was hired from the Nuclear Navy program. These individuals were well trained, and knew how to write and follow procedures. They were also adept at contamination control. The members of the Hazards Control division had strong academic credentials and experience in their disciplines.

Hazards Control was involved in work planning from early on. When planning work, there were discussions on how to perform the task, including experimenters, operations, and safety. Those involved had to agree with the proposed process prior to proceeding. This process was similar to the current-day Integrated Safety Management System (ISMS) program. Routine and special jobs were evaluated by a multidisciplinary team (e.g., workers performing the job, Hazards Control, and management). Field Hazards Control was responsible for identifying the hazards and establishing the controls.

The facility safety procedures provided general instructions and requirements for the particular building. Operational Safety Procedures (OSPs) include requirements such as types of monitoring, air sampling, personal protective equipment (PPE), and other radiological controls for specific experiments or operations within the facility. Also included was a description of the work to be performed, identification of hazards, quantity of hazards where applicable, and controls required for the work. Essentially, they informed the program what they needed to do to control and monitor radiation exposure and to perform the work safely. The OSPs are similar to a current-day work package and were used for specific jobs. Discipline Action Plans provided day-to-day instructions for health and safety technicians. For example, it would explain required surveillances for health physics, industrial hygiene, and industrial safety. These documents were reviewed on an annual basis or more frequently, as needed. Technicians were rotated through the different facilities to give them a broad knowledge of hazards and hazards controls at LLNL.

A Health Physicist was required to prepare a Health Physics Program document, which was updated annually. The Team Leader reviewed these for inconsistencies between plans. These included information on the location of the air samples, air sampling requirements, survey procedures, etc. Part I of the document provided general descriptions. Part II had detailed instructions for the H&S Technician. The overall Health Physics plans were generic in nature. The facility plans were adapted with specific information pertaining to the building. Industrial hygiene, industrial safety, environmental monitoring, and fire protection requirements were also developed in similar plans.

There was also a Hazards Control Manual and an H&S Field Techniques Manual. The Hazards Control Manual goes back to the 1970s. It included procedures for calibrations and calibration checks, routine technical work, and formal training material.

The AEC/DOE standards (e.g., AEC 0524 Manual, 5480.11, 10 CFR 835) have formed the basis of the radiation protection program at LLNL. The Radiation Safety Program has been somewhat challenging at LLNL, because R&D at the site is continuously changing. Monitoring worker doses and the work environment did not depend on only one system to determine whether exposures had occurred; it included personnel dosimetry (including extremity dosimetry), bioassay, WBC, air sampling, swipe surveys, hand and foot counters, area surveys, etc. Approximately 10% of the laboratory population handled or worked around radioactive material or radiation-generating devices.

Site experts indicated that LLNL had a good As Low As Reasonably Achievable (ALARA) program. All aspects of exposure control (i.e., time, distance, and shielding) were considered when developing radiation controls. For example, in the plutonium areas, Pb aprons were not

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routinely used while Pb gloves were used. The gloves caused reduced dexterity, resulting in a longer exposure time. Both the shielding protection and the increased exposure had to be considered. The Area HP was originally responsible for this function, but the programmatic individuals became involved at a later date, and Area HPs became peer reviewers. Tents were used where there was the potential for significant contamination, such as when first stage HEPA filters were changed.

Former radiological control staff indicated there was no tolerance for performing routine work in contamination areas, which occurred at some of the other (production) facilities. Contamination was cleaned up as it was identified. Airborne contamination areas were the exception and not a routine condition. Eating, drinking, and smoking were not allowed in the plutonium facility or other radioactive materials handling areas.

In general, areas of the laboratory where radioactive materials were handled or radiation generating machines were used were restricted to those individuals whose work assignments required their entry into the area. Former radiological control staff commented that it would be rare that any administrative staff or security personnel would enter into radiation areas, and essentially never into contamination areas.

Air sampling was primarily used as an indicator or to verify the adequacy of workplace controls. There was infrequent personal (lapel) air sampling for the purposes of health physics. Personal (lapel) air sampling was used when individuals were entering a known contamination area to confirm adequacy of the respiratory protection. This type of air sampling was routinely done to measure industrial hygiene hazards. Early personal air samples were collected using a carbon vane pump, which was moved around on a cart. Tubing was strapped to the individual's shoulder to reflect the breathing zone. Area air sampling was used much more frequently than lapel air sampling. Continuous Air Monitors (CAMs) were installed in the plutonium facility at the exhaust points to the HEPA filter. At a later date, they were installed in the immediate work areas. LLNL has not used DAC-hour tracking as a means of tracking dose. Particulate air sampling was conducted in areas where metal tritides were handled. Filters were counted with a liquid scintillation counter. Air sampling was not used for internal dose assignments; the variables affecting air sampling were too extensive.

Protective clothing for many areas was job-dependent. In some areas, workers wore lab coats and booties; in other areas, full Anti-Cs (i.e., coveralls, gloves, hoods, booties) were worn. During maintenance operations, full Anti-Cs were used. Respiratory protection (e.g., positive air purifying respirator, supplied air) was also used to some extent, based on the job hazards. In general, respirators at LLNL were worn for protection against chemical hazards rather than radiological hazards. There was a qualitative fit-test program using smoke and smoke tubes prior to the early 1990s. Starting in the early 1990s, a quantitative fit-test program was implemented using a PortaCount. Alpha friskers were mounted on each glovebox for routine hand monitoring. Hand and foot monitors were used for detecting personnel contamination when exiting the area. Site experts did not indicate they received chemical exposures in conjunction with radiation exposure.

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Portable survey instruments used at LLNL varied over time. A few of the survey instruments used in the 1970s are listed below:

Technical Associates Juno
Early Victoreen Ion Chamber
Blue Alpha Meter
Rem-meter

The Juno is a high-range rugged instrument for monitoring dose rates. The ion chambers are used for measurement of low-energy x-rays. The Blue Alpha Meter was used in the plutonium area and continues to be used today. One unique characteristic of the probe is that the active area is exactly 100 cm^2. Neutron instruments developed at LLNL included portable survey meters and spectroscopy units.

Beginning in early 1980s, the Radiation Safety Division of the Hazards Control Department had an X-ray Safety Officer who monitored the non-medical x-ray machine safety program. This individual is responsible for inventorying all units, ensuring that periodic inspections and interlock checks are completed, verifying the presence of the x-ray safety boxes (where required), and making confirmatory survey measurements. The x-ray safety boxes were attached to the units to shut down the machine if short circuits or other potentially hazardous failures were detected. X-ray safety became much more rigorous following a significant overexposure to x-rays at the LBNL in the late 1970s. The X-ray Safety Officer maintains these surveys and the registrations for the equipment.

Radiation Safety during Weapons Testing

During tests at NTS, PPG, and other test sites, dosimetry was provided by REECo (PPG and NTS) or Eberline (Tonapah, Cannikin (Amchitka), Gasbuggy (Colorado). The LLNL dosimeter was not worn while at the test site. Dose information for LLNL employees was sent to LLNL. There was an effort to go back and review previous results for LLNL personnel involved in testing. This included re-evaluating film and incorporating NTS dose into dosimetry files. Some amount of internal dose reconstruction was also completed. The underground nuclear test shots themselves were monitored by an array of radiation area monitors (RAM) during underground testing to check for the possible escape of fission gasses.

There were a variety of radiological hazards associated with weapons testing. During the atmospheric testing, there was prompt radiation. For underground and atmospheric testing, there was radioactive fallout. The fallout was disbursed by the wind. As a result of testing, the entire site was/is contaminated to some extent. With the 40–45 years that have passed since atmospheric testing, there has been radioactive decay of some radionuclides. Individuals working in the earlier years were exposed to more material than those there today. Some radionuclides are more prominent at NTS (e.g., Sr-90 and Cs-137). Some areas, such as Buckboard Mesa, are off limits due to contamination in the high lands.

Once the device and diagnostic systems were moved out into the "forward" GZ test area, personnel had to go through numerous security check points. In general, the closer anyone got to

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the GZ area, security and radiation safety became more rigorous. In addition to heightened security in the GZ area, there was always the appropriate number of Hazard Control personnel "monitoring things," according to site experts, for both pre- and post-shot. Hazards Control personnel at NTS entered tunnels to recover air samples and conduct measurements. Required PPE included a full-face respirator and coveralls. Typical instruments used for measurements included a Juno detector, Radectors, and an E-120. In addition to re-entry operations, Hazards Control also provided monitoring coverage during assembly. Site experts indicated that on post-shot re-entry or sample recoveries, it was assumed that the Hazards Control personnel directed and monitored individuals appropriately. There were situations where the recovery team members received overexposures. In general, Hazards Control staff observed that radiation safety recommendations were always followed. There were occasions where people overstayed their exposure time to "finish up" some operation. And there were times that radiation suits got torn or respirators leaked, but re-entry work, barring relatively common, unexpected situations, was reasonably planned and executed. With some exceptions, personnel wore their dosimetry badges in the "GZ operational" areas.

Upon exit from the area, the PPE was stripped off, cursory personal monitoring was done, and skin was decontaminated as necessary. Urinalysis was taken after personnel contamination was detected. No thyroid counts were conducted at NTS for LLNL workers interviewed. There was no routine or confirmatory bioassay upon return from test sites. The exposure at these sites was primarily to short-lived radionuclides.

External Monitoring

Site experts indicated that senior management at LLNL apparently did not want to have to answer workers' questions about potential exposures. It was believed that as a result, they implemented a policy to assign beta/gamma dosimeters to all LLNL workers. Site experts as far back as the late 1950s remember all laboratory staff being assigned dosimeters. Neutron dosimeters were assigned based on the workers' potential exposure to neutrons. The local DOE office set a policy that personnel were not allowed to receive more than 20% of the legal limit.

The dosimeter was, for a period of time, combined with the Security Badge. This combined system only measured beta/gamma exposure. It was either clipped under PPE or worn on a lanyard. In order to prevent the badge from getting caught in machines or contaminated, workers would sometimes throw their dosimeter to their back. Workers wore their dosimeters unless they accidentally forgot it when entering the area. There were some concerns raised by site experts that dosimetry was improperly loaded at times.

Significant exposures were received during work at the test sites and during the analysis of test core samples. The exposure received by personnel for core samples was dependent on the quality (amount of radioactive material) of the sample collected. The major source of Sr-90 at the lab was from core samples brought back to the laboratory for analysis. However, the majority of the radioactivity in the shot samples was from short-lived fission products. Drill backs had to be analyzed quickly, because of the short-lived radionuclides. This resulted in intense work for short periods of time at high dose rates. Some early chemists received a majority of their external exposures from core-handling operations and post-test air monitoring analysis. Routine extremity dosimetry was eventually implemented for Nuclear Chemistry. Prior to this, there was some indeterminate level of extremity monitoring. Some extremity dosimetry was worn by maintenance personnel.

Reactor Operators were on a monthly dosimeter exchange cycle. Dose reports were provided so individuals could monitor their dose throughout the year. The primary source of external exposure was from irradiated targets. Standing at the top of the reactor did not result in much exposure. Fuel change out was done underwater, resulting in minimal exposure. There was a less-frequent dosimeter exchange period for maintenance personnel, since they were considered peripheral. Routine extremity monitoring was implemented for some periods of time for those at LPTR removing targets from the reactor. In 1971, LLNL undertook a project to refurbish the vessel and perform extensive maintenance at the LPTR 3 MW Research Reactor. There were a lot of personnel rotated through this project. The highest annual cumulative worker dose (100–150 person-rem) for the laboratory occurred as a result. No worker exceeded the annual exposure limit.

In the late 1960s, concern was raised that the NTA film was not adequately measuring neutron exposure in the Critical Test Facility (Building 261) where critical array studies were being performed. As a result, a comparison of neutron doses recorded by NTA film and neutron rem meters was made. Neutron-to-photon dose rate ratios were evaluated in various assembly configurations. Based on the results of the study, the neutron-to-photon dose-rate ratios were used to determine the dose of record. In the early to mid-1970s, the site transitioned from NTA film to albedo dosimeters. Neutron spectral studies were conducted in the early 1970s. Neutron-to-photon ratios were established in the plutonium area by glovebox. The use of chemical track-etch detectors for neutron dosimetry was implemented in the 1980s.

The radiation profile of areas was evaluated on a regular basis. Night health and safety technicians would conduct periodic swipe characterizations of the radiological areas onsite in addition to the routine survey program. LLNL staff was heavily involved in testing new neutron measurement equipment and personnel dosimeters and determining neutron spectra for various areas of the site. In general, fission neutrons were typical in areas with Cf-252 sources, Cm-244, and plutonium. The Rotating Target Neutron Source (RTNS) II in Building 292 was used to produce 14 MeV neutrons from the Deuterium-Tritium reaction. Outside the RTNS II shielding vault, the neutron energies were about 1–2 MeV. This area inside the vault was not occupied during operation. Calibration of neutron instruments and dosimeters was done with a Cf-252 source (i.e., a fission neutron spectrum). At the LINAC, neutron measurements were made at the entry above the accelerator while it was operating and in accessible areas.

Roving workers would not be a concern after 1958, since all site individuals were monitored. Both maintenance and security personnel were badged, like those working in the glovebox area, if they were assigned to the Plutonium Facility or routinely entered this area. Personnel were required to show a security badge to get into the “forward” areas, so personnel generally wore their dosimetry badges. There were some exceptions.

Administrative staff was not always provided a dosimeter. There were situations where these individuals served as escorts to dignitaries or where offices were located near radiological areas.

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For example, one office area was located on the air station runway, which was later found to be contaminated.

Secondary dosimetry was routinely used at the reactors, accelerators, and radiography areas (remote or permanent). Secondary dosimetry consisted of digital ion chambers, chirpers, and traditional pocket ionization chambers. Some hot jobs (e.g., work inside the hot cell) required time limits and chirpers. The approach was to limit the time and to have knowledge of the dose rate. The results of these dosimeters are found in the technician logbooks. The radiography group maintained their own log of secondary dosimetry results. Mapped surveys were posted at the entrance to an area to inform the workers. They were updated when there was a modification to operations or material being handled.

In at least one case, a mechanical engineer asked health physics to re-evaluate the dose he received from working on parts from a prompt burst reactor at NTS (Super Kukla). There was a recorded gamma dose, but there was no beta exposure data in his record, so it had to be reconstructed. An extensive interview with the employee was conducted regarding the details of his job. Both skin and extremity doses were reconstructed and assigned to the employee's dosimetry record.

Internal Monitoring

A wide variety of radionuclides were handled at LLNL, including plutonium, uranium, tritium, curium, americium, mixed-fission products, other transplutonium elements, and numerous activation products associated with the accelerator programs. Tritium was handled in Building 331, the Laser Fusion Program facilities, Site 300, and at the accelerators. Tritium handled at LLNL was primarily in the form of tritium gas and salts. For example, titanium tritide was tied to target material used in Buildings 212 and 292. Other tritides handled include uranium tritide and LiDT. LiDT was primarily used in testing. Uranium tritide was handled in Building 331. Tritium was handled too casually. Uranium was also considered to be harmless and was handled without gloveboxes. In fact, the workers performed hands-on operations with uranium metal. Tracers used in the nuclear test shots were various transuranics. There were only minor projects involving work with radium and radon. Careful measurements were made of naturally occurring radon concentrations in all of the buildings at the laboratory. Thorium compounds were handled in gloveboxes in Building 241. Smaller quantities of thorium were handled in Building 151 and Building 222. Chemists worked with small amounts of radium in experiments. There were also some situations where encapsulated radium sources leaked. The laboratory produced very pure Pu-238 and Pu-239 with very low concentrations of Am-241. Chemists also conducted isotopic separations to produce new transplutonium elements. There were opportunities for precutaneous, ingestion, and inhalation intakes when coming in contact with fallout and with entries into tunnel complexes at NTS.

Chemical forms of plutonium handled at LLNL included plutonium hydrides, metal, oxides, and nitrates (smaller quantities). No high Pu-240 content material (i.e., <5%) was brought into the laboratory, because scientists didn't want to contaminate the Pu-239 stream. Plutonium-238 was handled in pure form in gram quantities. This was used as a test diagnostic tool. There was no production of heat sources at LLNL. Depleted and enriched uranium were handled in the form of metal, oxide, and a D-38 liquid. Some work was done with polonium oxide. Many of the radionuclides produced at LLNL for experiments (e.g., cross-section studies) were in R&D quantities.

The internal monitoring program at LLNL was constantly improving. LLNL developed an underground in-vivo counter for counting individuals exposed to uranium and plutonium. Health Physicists quickly discovered that the physical size of an individual affected the efficiency of the in-vivo counter. In the 1970s, LLNL developed a realistic phantom to obtain calibrations, which were reflective of parameters such as lung thickness and purity of material. Calibrations were available for various lung thicknesses. The extent of WBC implementation was variable, depending on the time period. For example, scientists involved in intermittent work at Site 300 do not recall receiving WBCs. There was some counting performed within 1 month upon return after the Amchitka event, but this was not the case immediately following all test events.

Bioassay was incident-based, with some exceptions. Routine bioassay varied by area, and was based on types, quantities, and forms of the radionuclides handled and the types of work being done. Approximately 90% of the laboratory employees did not handle radioactive material and were not on a routine bioassay program. Routine plutonium and tritium bioassay occurred for those working in the plutonium and tritium facilities. Plutonium workers submitted bioassay samples monthly, semi-annually, or annually, and received an annual lung count. Plutonium-239 was the predominant radionuclide, with minimal Pu-238 present. Site experts indicated that tritium was not taken as seriously as some of the radionuclides onsite, because it didn't really pose a dose problem. Routine tritium bioassay for Building 331 workers was done weekly for individuals with high exposure potential, and monthly for those with peripheral involvement. Employees working around the firing tables at Site 300 were monitored for uranium uptakes; however, this may have varied over time. Individuals involved with Site 300 tests in earlier years (e.g., 1950s, 1960s, and 1970s) recall having film badges for measuring external dose, but do not remember submitting urine or fecal bioassay. Uranium bioassay programs were implemented for workers involved in machining and metallurgy at Building 321C shop and Building 231. Individuals handling core samples were monitored for mixed-fission products and transuranics as deemed necessary. Historically, uranium urinalysis was not effective enough by itself to allow for internal dose reconstruction. Various enrichments of uranium were handled, so there had to be some information on the type of material to which a worker was exposed. Monitoring requirements were documented in OSPs.

Special bioassays were also taken when there was an unusual occurrence (e.g., elevated counts on air filters, glovebox failures, and unexpected releases). During the early days (the 1950s and 1960s), special bioassay sampling was determined in consultation with the Medical Department. The Bioassay Program was moved entirely to the Hazards Control department in the early 1970s. Currently, there are flow sheets available in the LLNL internal dose TBD for determining when special bioassay sampling is required. When an incident occurred, the Health Physicist requested a sample of material from the area of potential exposure for isotopic analysis. Samples were counted prior to and after radiochemistry processing, and could include urine and/or fecal sampling.

Nose smears were taken primarily as a field indicator for potential internal contamination. In the earlier years, the decision to take nose swipes depended primarily on the professional judgment

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of the area Health Physicist. In about 1990, a more formal protocol for taking nose wipes and other follow-up bioassay samples was developed, based on airborne contamination levels, breaches in glovebox gloves, surface contamination levels, etc. In many cases, nasal smears are not indicative of actual intakes. There are individuals with positive nasal smears who have negative bioassays, and individuals with negative nasal smears who have positive bioassay. Regardless, anyone with a positive nasal smear was sent for bioassay, which was the basis for internal dose assessment.

There were no chelation events at the site prior to about 1990; however, there have been about five or six chelation events since that time. This has largely been the result of incidents associated with the handling and processing of legacy waste.

Environmental Monitoring and Waste Management

Environmental monitoring was originally part of the Hazards Control Department. The 1969 fire at RFP precipitated an expansion in the Environmental Monitoring Program at LLNL. Early environmental monitoring included collecting air samples at the site perimeter, soil sampling, groundwater sampling, and measurement of external exposure by ionization chambers and later thermoluminescent dosimeters (TLDs). Environmental monitoring has improved (kept up with the state of the art and increasing requirements) over time. In the mid-1980s, the Environmental Protection Division was formed, separating this function from the Hazards Control Department, and now consists of several hundred employees. There have been a number of issues at LLNL associated with environmental releases. The Environmental Protection Agency (EPA) has brought up concerns regarding tritium in the drinking water.

Historically, waste separation was not as rigorous as required by regulations today, and, by current standards, it was poorly characterized. A few of the waste-handling facilities include 512 (Old Liquid Waste Facility), the 612 Complex, and 514 (Current Liquid Waste Facility). Low-level waste was stored in Bennett buckets. Some of the early waste had to be repackaged by Waste Handlers. The drums were opened in a walk-in hood, and the contents were determined and repackaged into larger containers. With this work, there was an expected contamination hazard. As a result, coveralls and respiratory protection were used. The drums are then sealed and characterized prior to shipment to waste management. Aerial surveys of the site did identify some hot spots on the Livermore site. The military had buried radium dials onsite when they owned the site.

Incidents

The LLNL Fire Department is responsible for occurrence reporting and also maintains the incident archive at the Fire Station (Building 323). These reports are organized by incident number and year. When an incident occurred, the department involved was responsible for generating a report. Unusual events or identification of unexpected sources of exposure were supposed to be documented. Incidents mentioned by site experts include:

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- Criticality Accident
- 1965 Release (Tritium)
- 1970 Release (Tritium)

On March 26, 1963, a criticality accident occurred in Building 261 in a shielded vault designed for criticality experiments. At the time it occurred, no personnel were in the vault area. There was an explosion equivalent to 6–10 pounds of dynamite. The criticality was stopped when the explosion occurred, because there was no longer a favorable configuration. This facility was used to conduct fissile material array studies. Experiments were conducted in a shielded room with 5-foot thick concrete walls.

The largest environmental releases at LLNL took place in 1965 and 1970, when tritium gas was released to the atmosphere. At the time, tritium stack monitoring was performed using an ion chamber with a strip chart recorder to help determine the magnitude of the release and sound alarms. In 1972, catalytic converters and molecular sieves were installed to supplement the ion chambers. The catalytic converters were installed to convert tritium gas to tritium oxide, which was easily collected on the molecular sieves. There was a known tritium release to the ground near the old reactor building onsite. Tritium could be measured in neighboring vegetation (e.g., Tritium Tree) until the area was remediated. An early incident at LBL resulted in an increased rigor in the x-ray safety program at LLNL.

In 1967, a release of 32 mCi of plutonium-239 to the sewer system occurred. During review of sewer sampling data, a spike of plutonium was observed. The material made its way to the Livermore sewage treatment plant, where it got deposited with the sludge. This sludge was sold to the public for use as fertilizer and soil conditioner. Some of the sludge was sold prior to the cleanup and was used in Big Tree's Park. Once the situation was discovered, the city was notified. Monitoring of the sludge indicated detectable quantities of plutonium on the order of a few pCi/g. The extremely low levels of plutonium in the sludge were considered a negligible risk, and no limitations were put on its use by the public. Around 1990, traces of plutonium were found in a public park close to the laboratory as part of LLNL's Environmental Monitoring Program. LLNL did extensive sampling of the park to determine whether the sludge was contaminated and what potential exposures may be to the public. The maximum concentrations detected in a small area were on the order of 1 pCi/g. Due to the finding and concerns raised by a small group of citizens, extensive studies were completed on the extent of the contamination and the potential exposure pathways. Studies by the State of California, LLNL, and the Centers for Disease Control (CDC) concluded that the risk associated with the contamination was of no health concern. One of the changes that occurred as a result of the release was the installation of a real-time sewer monitoring system. A formal LLNL report was issued regarding this incident.

In about 1960, a spill involving fission products at the LPTR occurred, resulting in the spread of fission product contamination. A uranium spill occurred in 1986 or 1987 to a trench outside Buildings 491 and 493. An incident analysis report was written on this release and would provide further detail.

In addition to those incidents occurring at the main LLNL site or at Site 300, LLNL individuals were involved in incidents at testing sites. For example, the Baneberry underground test resulted in a tremendous venting to the atmosphere. Curies of radioactive fission products associated with the detonation of the device were released. This test resulted in a stand-down and a reduction in testing once it was restarted. During Greeley, two workers were sent down the shaft in a special basket prior to the shot. The firing cables were damaged as a result of test preparation. Then men were sent down the shaft to repair the cables.

Records

Health Physicists and technicians kept logbooks of daily activities. Exposure information from the 1950s and 1960s were recorded in the technician's, supervisor's, or team leader's logbook (e.g., Hazards Control logbooks). Logbooks were organized by individual or area, depending on the time period. These logbooks are rich with exposure information until about the late-1960s. There is a huge archive of memoranda, logs, and procedures about plutonium operations located at the plutonium facility. Logs from other buildings are stored elsewhere. Some health physics records were transferred to Site 300 for storage. No radiological records were ever intentionally destroyed.

Hazards Control maintains a database of internal and external dosimetry results. In-vivo counting records are all available on computer media. The MAPPER database was developed in the early 1980s to organize, store, and make dosimetry information readily retrievable. It included internal and external dose information. Essentially all internal and external doses received at the site (and offsite), per radiological control staff, are included in this database. There was an effort to reconcile the individual dose values with the cumulative dose records. The personnel monitoring data included with classified records was separated from the classified information and declassified.

TBD Comments

SC&A asked for clarification on technical basis document comments related to destroyed, misplaced, or inaccurate records. The primary concern of Tri-Valley Cares is that records are incomplete with respect to exposures received at the test sites. They are having difficulty demonstrating that individuals were at NTS or other shots, and for how long. They have tried to retrieve airplane trip records to demonstrate that individuals actually went to the site; however, DOE has not been able to provide these. Other former workers have been told that records such as job assignments have been destroyed. The Oak Ridge Associated Universities team has visited Tri-Valley Cares to review their records collection.

Miscellaneous

LLNL had a presence at Pantex and RFP. While there, individuals were monitored by the respective sites. About 1 in 15 experiments conducted by LLNL involved Pantex. In the 1950s and 1960s, a few individuals who visited the RFP and Mound laboratories received 10s of rem from internal exposures.

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Family members of scientists were invited in the past to visit NTS. They were shown the Sedan crater, which resulted from a 100-kiloton nuclear shot. They were only able to stand on the platform for a limited amount of time (~10 minutes), due to the dose rates in the area.

Medical x-ray exposure was not routine. The worker physical did not require that an x-ray be taken.

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

SC&A submitted questions related to the LLNL Site Profile documents to NIOSH on November 9, 2006, with supplemental questions submitted on June 8, 2007. NIOSH/ORAUT provided written responses to these questions on December 6, 2006, and July 8, 2007, respectively. Both sets of questions and responses have been provided below.

Responses to SC&A Questions for the LLNL Site Profile Document:

Site Description TBD, ORAUT-TKBS-0035-2
Occupational Medical Dose TBD, ORAUT-TKBS-0035-3
Occupational Environmental Dose TBD, ORAUT-TKBS-0035-4
Occupational Internal Dose TBD, ORAUT-TKBS-0035-5
Occupational External Dose TBD, ORAUT-TKBS-0035-6

The current versions of these TBDs were published with acknowledged data gaps in information to allow processing of selected LLNL claims. Planned revisions of these documents will include additional information collected since the publication of this TBD and any applicable information that comes from NIOSH responses to SC&A questions.

Key Questions for NIOSH/ORAU regarding the Lawrence Livermore National Laboratory Site Profile Technical Basis Documents

[Submitted by the SC&A review team, November 9, 2006]

General Questions

(1) Is there a classified version of the Technical Basis Document?

> ***Response:*** *There is not a classified version of the LLNL Technical Basis Document (TBD). Also at this time, no classified documents were reviewed prior to the development of the LLNL TBD.*

(2) In general, what subject areas could not be included in the TBD for national security reasons? How were these compensated for in the TBD?

> ***Response:*** *The mass of fissile materials were not available for specific devices. The specific procedures and nature of the experiments were not available for review in unclassified documents. The measured neutron to photon dose ratio for specified nuclear devices and components were not available. Personnel exposure to ionizing radiation, both internal and external exposures, was documented using the technology and criteria approved for that period of time. There was sufficient information to establish radiation exposures for personnel working with classified materials. The current TBD addresses what are believed*

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

(3) What steps were taken to investigate whether individuals at LLNL also received doses at the Nevada Test Site, Trinity, and other test sites? Is dosimetry information from these other facilities available in the LANL radiation exposure file?

Response: *Personnel at LLNL did work at the Nevada Test site (NTS) as well as the Pacific Proving Ground (PPG). If it is determined that the individual was at one of the test sites, monitoring results are requested and received from the site. The claimant files will then contain the radiation monitoring results from NTS or PPG and are included in the records used by the dose reconstructors. Assumptions to reconstruct radiation dose are summarized in the TBD developed for NTS.*

(4) Was there movement of personnel and radiological activities between LLNL and Sandia National Laboratory?

Response: *It is possible that personnel at LLNL did work at the Sandia National Laboratory (SNL). SNL established the requirements for personnel monitoring, including for visitors in their facilities. The claimant files contain the radiation monitoring results from SNL, as available, and would be expected to be included in the records used by the dose reconstructors. Assumptions to reconstruct radiation dose, for any Sandia site exposure, are summarized in the TBD developed for SNL.*

(5) Is any of the work history, medical, or radiation exposure data for claimants classified? Are claimant files being redacted for national security reasons?

Response: *The ORAUT has never seen any indication that information in a dosimetry response was redacted because of security classification.*

(6) What types of claims have been evaluated to date? Without a complete dataset, how has NIOSH/ORAUT bridged gaps and assured estimated doses are bounded?

Response: *Because of the lack of internal monitoring data in claimant files, claims, which are particularly radiosensitive, can not generally be completed using overestimating efficiency methods. The exception to this is claims were environmental internal radiation estimates (as provided in the TBD) are appropriate. This same limitation exists for claims with multiple primary cancer sites.*

A bioassay coworker study is currently underway to assist in determining internal exposure for individuals with a potential for internal exposure but for whom internal monitoring was not performed.

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Some claims are able to be evaluated using under- or overestimating techniques to account for the gaps in data. Others require more information and have not yet been completed. In the case of internal dose assessment, a number of claims have been put on hold while research continues into the interpretation of results and the identification of information to be used to fill the gaps in monitoring.

(7) Which Technical Information Bulletins are applied to LLNL dose reconstructions (e.g., TIB-0006, TIB-0002, TIB-0028)?

Response:

1. *OTIB-0002, Maximum Internal Dose Estimates for Certain DOE Complex Claims, 2004.*
2. *OTIB-0006, Dose Reconstruction from Occupationally Related Diagnostic X-Ray Procedures, 2005.*
3. *OTIB-0007, Occupational Dose from Elevated Ambient Levels of External Radiation, 2003. (This OTIB has since been cancelled. All relevant information is in ORAUT-PROC-0060, Revision 1, Occupational Onsite Ambient Dose Reconstruction for DOE Sites.)*
4. *OTIB-0017, Interpretation of Dosimetry Data for Assignment of Shallow Dose, 2005.*
5. *OTIB-0018, Internal Dose Overestimates for Facilities with Air Sampling Programs, 2005.*
6. *OTIB-0020, Use of Coworker Dosimetry Data for External Dose Assignment, 2005.*
7. *OTIB-0023, Assignment of Missed Neutron Doses Based on Dosimeter Records, 2005.*
8. *OTIB-0055, Technical Basis for Conversion from NCRP 38 Neutron Correction Factors to ICRP Publication 60 Weighting Factors for Respective IREP Input Neutron Energy Ranges, 2006.*

(8) How has NIOSH/ORAU verified the completeness and accuracy of the data provided by LLNL?

Response: *The TBD was developed using documents that were developed by LLNL and reviewed by the DOE. When available, multiple documents were referenced to provide consistency. To the extent practical, the TBDs are complete and accurate.*

It was extremely common for LLNL workers to visit NTS. When there is evidence of a visit occurring (whether in the claimant supplied information, CATI, or dosimetry information), a request for dosimetry information is sent to NTS.

(9) How have you integrated site expert input into the TBD?

Response: *Several individuals were interviewed to discuss specific elements of the radiation monitoring program at LLNL. Mr. Mel Chew* (NIOSH/ORAUT) *provided information about the radiation control program at Site 300 and the air*

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sampling efforts for tritium. [Name redacted] *provided a summary of the radiochemistry procedures for bioassay samples and internal radiation exposure. In 2004, the HSE department managers described current radiation dose assessment procedures. This information was summarized in the TBD. Contributions on internal dosimetry, external dosimetry, and medical exposures were incorporated based on discussions with current staff.*

Site Description (ORAUT-TKBS-0035-2)

(1) In Section 2.3.1 ["Building (Main Site)"], the TBD appears to be inconsistent in using the old and current building numbers to identify buildings. When cross-referencing buildings identified in this section with buildings in Table 2-1 and Attachment A, there is a lot of disagreement with building names. This gives the impression that the authors may have conflicting information.

> ***Response:*** *The term "Building Name," although used in the reference, should not be taken literally. In most cases, the name actually refers to "Building Function" or "Building Activity," and a building may contain several functions or activities. The term will be changed in the next document revision, and a more complete description of the numbering system reflected in the TBD will be included. The building activities came from several sources and may refer to different functions. Some buildings did not have "old numbers." Prior to issuing a revision all building numbers and descriptions will be verified.*

(2) Table 2-2 does not list Building 121which is a major building that is the first listed in Section 2.3.1.

> ***Response:*** *Building 121 will be added to Table 2-2 in the next revision of the TBD.*

(3) Table 2-2 shows Building 292 as having residual contamination from a rotating target neutron source, but the only radionuclide identified is ^{3}H. Are there any other activation products there?

> ***Response:*** *No long-lived activation products were identified in the references.*

(4) Table 2-2 shows Building 231 as containing "The-232" – can we assume this should be Th-232?

> ***Response:*** *Yes, this should be Th-232.*

(5) Table 2-2 is not consistent in showing radionuclide contents in buildings. For example in several places (Buildings 513, 514, 612, 625) ^{90}Y is not shown when there is ^{90}Sr although the pair are shown in other buildings, these two are always present together in equal activity unless chemically separated.

> ***Response:*** *This will be revised to be consistent.*

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(6) In Section 2.3.1, at the end of the sub-section for Building 231 there is a statement that, "Small amounts of DU have been used in Building 232." Is this meant to start a new sub-section on Building 232, or is this a typographical error and is it still discussing Building 231? Also, an example of what is meant by "small amounts" would be helpful (e.g., gram quantities?).

Response: *This question requires clarification. Building 232 is part of the Building 231 complex; however, this is not contained in the description.*

The following is an example of describing "small amounts" by using actual mass values:

- *in the case of DU, "small amounts" generally means less than 10 kg.*

(7) There is no section discussing Accidents and Incidents, such as in the LANL TBD. Does this infer that there were none of these?

Response: *Accidents and Incidents are described briefly in Section 5. This was also a Worker Outreach comment and further research has been performed to more fully describe Accidents and Incidents in a document revision of the LLNL TBD.*

Occupational Medical Dose (ORAUT-TKBS-0035-3)

(1) The Occupational Medical Dose TBD (Turner 2005, pg. 6) provided a quote from a 1991 document which stated that "…relevant medical history and X-ray procedure requested will be recorded on the radiographic request form. …" (LLNL 1991) Has NIOSH/ORAU routinely found from their claimant research this kind of relevant medical history and x-ray protocol routinely listed on the radiographic request form that is mentioned in the LLNL Health Sciences Department Radiography Program document cited in the TBD?

Response: *The x-ray records provided by LLNL include a list of the x-rays provided as part of the medical screening process. This record does not usually include the "relevant medical history" as mentioned in the document quoted above.*

(2) If an individual claimant's medical file lacks proper documentation of his chest x-ray history, has NIOSH/ORAU developed a default schedule to account for routine chest x-rays and if so, what is that default schedule?

Response: *Procedure 61, Occupational X-ray Dose Reconstruction for DOE Sites, provides a default frequency for LLNL of a pre-employment PA chest and annual PA chests for cases that are reconstructed using an "overestimate" approach. The guidance in Procedure 61 also states that x-ray records should be requested from LLNL and the case must be reconstructed using a "best estimate" or "underestimate" approach (if the records were not initially provided). LLNL has been responsive to such requests.*

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(3) Has NIOSH/ORAU been able to verify that LLNL workers did receive routine chest x-ray examinations during medical examinations? Since the TBD states that these were not routinely done and were only documented in the individual's medical record, what has been the experience in reviewing LLNL worker medical records on the frequency of these routine medical x-rays?

> ***Response:*** *The TBD is clear about the requirement for a pre-employment PA chest x-ray. Page 6 of the TBD states "From 1952 until about 1993, baseline X-rays were required for all pre-employment evaluations." Also on page 6 is the quote from the LLNL Health Services Department Radiography Program, March 1991 document which states "Based on the unique nature of the work performed at LLNL, a pre-employment baseline PA chest X-ray examination is required." As described in the answer to question #2 above, a default frequency of an annual PA chest in addition to the pre-employment PA chest for cases that are reconstructed using an "overestimate" approach is assigned, and the x-ray records can be requested from LLNL should they be needed in completing a case using the "best estimate" or "underestimate" approach. LLNL has been responsive to such requests.*

(4) Has NIOSH/ORAU found evidence of special chest radiography at LLNL and were LLNL workers given dose for special chest radiography for respirator certification, for beryllium and asbestos exposure and for food handlers?

> ***Response:*** *According to (Noonan 2002), "Required chest films for beryllium and asbestos workers were introduced in the 1980s. The frequency of which varied based on the age and exposure of the individual [sic]." This is the only documentation found on this subject. No evidence was found for required chest radiography at LLNL for respirator certification or for food handlers. However, as described in the answer to question #2 above, a default frequency of an annual PA chest in addition to the pre-employment PA chest for cases that are reconstructed using an "overestimate" approach is assigned, and the x-ray records can be requested from LLNL should they be needed in completing a case using the "best estimate" or "underestimate" approach. LLNL has been responsive to such requests.*

(5) What evidence has been found to rule out the possible use of PFGs in the early period from 1952 to 1960 other than the random sampling of seven LLNL worker's individual medical records?

> ***Response:*** *No records in any form were found to indicate that PFGs were ever performed at LLNL. Other efforts made to find evidence of possible PFG use all yielded negative results. The question of the possible use of PFGs was raised routinely with each LLNL staff member consulted during preparation of the TBD, without positive response. In addition, spot checks of individual records in the NOCTS files for LLNL were made and so far, have not turned up anything to indicate that PFG was used. Should a claim turn up with evidence of a PFG, the*

dose reconstructor would assign organ dose for the PFG from ORAUT-OTIB 0006.

(6) Is there any documentation on the number of retakes that were often needed, especially in the early days, when using the Fisher x-ray machine?

Response: *The only document found for the Fisher machine is the survey report discussed in the next item (Graham and Williams 1975). It did not address retakes. There is documentation showing that retakes were monitored in later years. However, no quantitative information from the results of any retake studies was found.*

(7) What is known about the maintenance schedules, radiographic safety protocols and optimal operating parameters of the Fisher x-ray machine used at LLNL from 1952 to 1980?

Response: *The only document found for the Fisher machine is (Graham and Williams 1975). This is a useful and informative reference in the form of an interdepartmental memorandum from the two surveyors to* [Name redacted]. *It describes results obtained from a radiation survey of the X-ray facility. In summary, the memo concludes, "The results of the radiation survey indicate that the X-ray machine is operating properly and that the facility is adequately shielded." Measurements were performed over a range of operating voltages (40 kVp to 100 kVp) at currents of 100 mA and 200 mA, with other parameters also being varied. To cite from the memo again, "The half-value layer measurements indicate that at 100 kVp and with the normal filtration (3 mm Al) the effective energy is 32 keV. This energy is appropriate for medical radiography." Apparently, the Fisher machine was thoroughly checked out and operated in an optimal manner at this time. There is no discussion in the memo of maintenance schedules or radiographic safety protocols. However, a copy of the California Radiation Control Regulations was included as an attachment to the memo, additionally suggesting good safety management of the facility.*

(8) What is known about the potential for LLNL workers to receive x-rays for other forms of radiation exposure, other than routine chest x-rays such as isotopes, sealed sources, radiography etc.? What impact on providing claimant-favorable occupationally related medical dose does the lack of defined protocols and specific knowledge of the radiography procedures have when assessing dose occupationally related medical dose to LLNL workers?

Response: *If the first question refers to "X rays for other forms of radiation exposure" as being those occupationally encountered, for example, in crystallographic work or in the inspection of welds, then such X-ray doses do not constitute occupational medical doses. These exposures are part of an individual's external radiation dose and would be addressed by Section 6 of the Site Profile. Per 42 CFR 81 and 82, the only occupational medical dose eligible to be included in dose reconstruction under EEOICPA is dose from x-rays that were required of* *employees, as part of medical screening and surveillance programs. The Occupational Medical TBD addresses organ dose from these procedures, and these procedures only, as prescribed by 42 CFR 81 and 82.*

ORAUT-OTIB-0006 was developed to provide default values for entrance kerma and organ doses when specific X-ray machine data from a site was either not available or suspect. The default values in ORAUT-OTIB-0006 are favorable to claimants, and are to be used when site specific data is lacking. The DCFs from ORAUT-OTIB-0006 (modified from ICRP 1982) were used with LLNL entrance kerma values prior to 1980. As described in Sections 3.4.3 and 3.4.4, adequate information was available for times after 1980 for the Xonics and Bennett machines to assess the skin-entrance kerma and then appropriately use (ICRP 1982) DCFs.

(9) What radiological safety procedures have been found to documents that LLNL applied dose minimization to reduce medical exposures prior to 1960?

Response: *The TBD team researchers focused their data collection efforts on obtaining information about the x-ray screening protocols, information about average technique factors used for screening examinations, and any physical measurement data made on the x-ray machines over time, so that site specific organ doses could be developed for the screening exams. While no specific documentation was found that pertained to efforts at LLNL to minimize medical X-ray exposures prior to 1960, this was not the primary focus of the researchers' data collection efforts.*

(10) Has any effort been made to validate the application of the DCF factors in the ICRP 1982 DCF tables to the early x-ray machines at LLNL, particularly before about 1970, and what has been done to compensate for the lack of collimation in this early period?

Response: *ORAUT-OTIB-0006, 2003 and 2005, specifically addresses the assumption of poor collimation for x-rays made prior to 1970. Prior to 1970, the authors of ORAUT-OTIB-0006, 2003 and 2005, recommend that DCFs from (ICRP 1982) other than those for the PA and LAT chest x-rays be substituted for certain organs in order to account for poor collimation. The substitute dose conversion factors are chosen (and documented in ORAUT-OTIB-0006, 2003 and 2005) to include more organs in the primary beam than would be the case for a properly collimated beam. For the pre-1970 dose to the thyroid, for example, ORAUT-OTIB-0006 recommends using the DCF for an AP cervical spine (appropriately correcting for difference in organ depth between the AP and PA projections), effectively placing the thyroid in the primary beam of a poorly collimated PA chest x-ray. DCF substitutions are also specified for the ovaries and analogues, testes, and uterus. Again, as related to LLNL, the claimant-favorable pre-1970 doses in Table 3-3 of the TBD are based directly on ORAUT-OTIB-0006, 2003 and 2005, and assume a poorly collimated beam prior to 1970.*

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(11) How did NIOSH determine that when no information is known about the energy spectrum, that it is appropriate to rely on Implementation Guide (NIOSH 2002a) as a basis document?

Response: *The External Dose Reconstruction Implementation Guide (NIOSH 2002a) gives the following instructions (p. 19). "If no information is known about the energy spectrum, they should be conservatively (claimant friendly) assumed to be in the 30–250 keV photon range." This is the middle of the three photon energy bands specified within the NIOSH-IREP probability of causation program, and the only appropriate energy spectrum range for the production of medical x-ray images. For LLNL, the operating potential differences (related to the maximum energy x-ray photon) and the entrance exposures for the x-ray machines were all documented.*

Occupational Environmental Dose (ORAUT-TKBS-0035-4)

(1) The LLNL Occupational Environmental Dose TBD (Thomas 2005, pg. 7, Section 4.1, Introduction) states, "There was a potential for ingestion of radioactive materials from resuspension of radioactive materials" (Section 4.3). There currently is no section related to this topic. Does NIOSH/ORAU intend to include a discussion and associated tables estimating annual intakes via resuspension of radionuclides of concern?

Response: *The potential for environmental dose was solely evaluated for the inhalation pathway; there was no assessment of the ingestion pathway. The current TBD addressed what was believed to be the major contributors to exposure, but as additional information becomes available and if it indicates modifications are warranted, information will be added to the TBD for use by dose reconstructors.*

(2) In future revisions of the TBD, what soil resuspension factors will NIOSH/ORAUT use to develop concentration and intake data for the ingestion pathway?

Response: *There was no assessment of the ingestion pathway. No soil resuspension factors are available at this time.*

During dose reconstruction for DOE sites, any environmental intakes of material are assumed to be from the inhalation pathway. Ambient doses are assessed using air monitoring data from environmental stations across the site.

(3) Has NIOSH/ORAUT identified locations where soil contamination exists in addition to the Pu-239 contamination in the Southeast quadrant of the Main Site?

Response: *No, the environmental monitoring chapter summarizes the results provided by the onsite air sampling network.*

(4) The LLNL Occupational Environmental Dose TBD does not provide information regarding episodic (acute) releases that may have resulted in unaccounted for intakes or external

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radiation exposure to unmonitored workers. Does NIOSH/ORAUT have information to this effect and if so, how will this information be included in future revisions of the TBD for use by dose reconstructors?

> ***Response:*** *Environmental doses are only used to estimate doses for unmonitored workers, who would not have required radiological monitoring. A spill or acute release required monitoring for the persons involved in the release or associated with the remedial work. Radiation dose associated with acute releases and/or episodic releases are defined in the individual claimant file. The current TBD addressed what we believed to be the major contributors to exposure, but as additional information becomes available and if it indicates modifications are warranted, information will be added to the TBD for use by dose reconstructors.*

(5) The LLNL Occupational Environmental Dose TBD (Thomas 2005, pg. 15, Section 4.2.3.1, Potential Intakes Prior to 1961) states, "Prior to 1961, air monitoring data were not available for review… Efforts are currently in progress for developing intakes that occurred prior to 1961 and may be presented in a future revision of this TBD." What progress has NIOSH/ORAUT made to estimate worker intakes prior to 1961 (1952–1960 for LLNL and 1955–1960 for Site 300)?

> ***Response:*** *Revision 01-E (June 26, 2006) was revised to address the potential environmental dose prior to 1961. The environmental data from Argonne National Laboratory East (Site D) (ORAUT 2006) was used because no data were collected at LLNL until 1961. The assumed geometric standard deviation (GSD) was 5.0 because the results were not collected at LLNL. The maximum value was selected from the dataset, 1953 through 1960 and added as a surrogate for 1952 at LLNL.*

(6) The LLNL Occupational Environmental Dose TBD (Thomas 2005, pg. 16, Section 4.2.3.2, Potential Intakes 1961 to 1971) states, "Tritium environmental air monitoring data were not available for review. Estimated worker intakes of tritium in this revision of the TBD are restricted to the years beginning with 1972. Efforts are currently in progress for developing tritium intakes that occurred prior to 1972 and may be presented in a future revision of this TBD." What progress has NIOSH/ORAUT made to estimate worker tritium intakes prior to 1972?

> ***Response:*** *Environemtnal air-monitoring samples were not analyzed for tritium prior to 1972. Most of the tritium released was airborne with the dominant source being the Tritium Facility (Building 331, previously Building 172) which began operation in 1952. The TBD was revised to estimate inhalation of tritium by using dispersion models that were developed by LLNL to support a dose assessment after a release of tritium in 1970. Using the dispersion calculations that were performed in 1970, the estimated annual release of 200 TBq/year and the same weather conditions that existed during the release, the concentration of tritium is estimated to range from 5.8 Bq/m^3 to 2 x106 Bq/m^3 for any given year, from 1952 to 1971. It is unreasonable to assume that any one person stayed in*

the exact location (immediately downwind of the Building 331 stack) for the entire exposure period of twenty (20) years, that the weather conditions did not remain stable and consequently, or that the maximum concentration represents the potential exposure. Revision 01-E (June 26, 2006) provided these data in Tables 4-3 through 4-7. Using the maximum airborne radionuclide concentration in a year (from either actual data or an estimated value), annual intakes for the radionuclides of concern were derived by using an assumed individual's annual respiration rate of 2,400 m^3/yr.

(7) The TBD identifies that effluent data collected in 1976 and later have an estimated uncertainty of ±20%. In future revisions of the TBD, will NIOSH/ORAU demonstrate that this value is conservative given the inaccuracies of early year data and data that still require reconstruction for intakes prior to 1961 and for tritium intakes prior to 1972?

Response: *The uncertainty associated with the monitoring data is related to the collection and analysis of the individual samples. There are no data available to establish the uncertainty associated with the potential for environmental exposure for unmonitored workers at LLNL. If additional information becomes available and if it indicates modifications are warranted, information will be added to the TBD for use by dose reconstructors. Because of known uncertainties associated with measurements and their application in extrapolating to dose, a lognormal distribution is used for assigning dose, with a default GSD of 3. As noted above, a GSD of 5 is assigned for the early years because data from a surrogate site has been applied.*

(8) Is there any information regarding source accountability (i.e., loss of control of radioactive sources) that may have contributed to exposures of unmonitored workers?

Response: *No, the environmental monitoring chapter summarizes the results provided by the onsite air sampling network. The assessment of the release of tritium from Building 331 was used only to estimate exposures prior to the startup of the air monitoring network*

Occupational Internal Dose (ORAUT-TKBS-0035-5)

(1) How will NIOSH review the bioassay database for accuracy (verification and validation)? LLNL had warned NIOSH in the letter that accompanied the database that it is known to contain errors.

Response: *The database is used only for the coworker study; individual claims use the hard copy records that are provided by the site. LLNL included a list of specific concerns regarding the electronic data and multiple conference calls were held to discuss interpretation of the data. All assumptions and exclusions will be documented in the coworker OTIB.*

(2) How will NIOSH determine the quality and usefulness of the earlier bioassay data (laboratory quality control, knowledge of result units and sample sizes, radionuclides assumed to produce the gross alpha and beta results, etc?)

Response: *This is typically a generic issue across the complex. Records from the site are reviewed to the extent that they can be found and assumptions are made where necessary and possible. It's unclear as to why there would be an issue associated with result units; those are typically included with results. The interpretation of gross alpha and beta results was discussed with site personnel during the calls to address the database – a former chemist from the site participated in the discussions. Based on knowledge of what could have been included in the sample and what would have been chemically removed, the list of alpha emitters is small enough to limit the choices and determine a default. The gross beta results are more problematic and a solution is still being discussed.*

(3) How will NIOSH reconstruct internal doses for groups that did not get adequate (or any) bioassay monitoring and were potentially exposed to airborne and/or transferable surface contamination (including the early years that did not have bioassay procedures)? Is there air sampling data or other contamination survey data available for this assessment?

Response: *A coworker study is in development for the years in which bioassay was performed. Bounding estimates can be placed on individuals with the potential for intakes of long-lived, long-retained nuclides who worked during the years preceding the implementation of a bioassay program and who were subsequently monitored in later years. An approach is still in development for unmonitored workers in the early years with no later monitoring or with the potential for exposure to short-lived nuclides, such as fission and activation products.*

(4) For bioassay of radionuclides that occur naturally (uranium, thorium, etc.), how will NIOSH handle the determination of the occupationally contributed component of the activity in the bioassay sample in a claimant-favorable manner? Should the average background for the population be used or an individual specific background (if available)? Is the average value the most appropriate to use or the – one standard deviation (σ) value for background subtraction?

Response: *When assessing intakes based on uranium urinalyses, our standard procedure has been to assume that the entire result is due to occupational exposure because of the large variability in the natural background and its dependence on personal habits (such as drinking water source) of the individual.*

In the case of Cs-137, we are using values from the NCRP as a guide and not assessing whole body count results below those values. However, we do not subtract the value when it is determined that an occupational intake occurred.

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(5) NIOSH states that LLNL handled a lot of tritium compounds. Has NIOSH attempted to verify any usage of metal tritides or organically bound tritium compounds at LLNL? How will NIOSH direct dose reconstructors to perform internal dosimetry for these compounds if these were handled?

> ***Response:*** *It is not known if metal tritides were handled at LLNL, and if they were, what quantities and what processes were involved. In general, tritium tritide contributes little dose unless there are large quantities of contamination found in the work place. The TBD shows that, with one exception, tritium dose is calculated and assigned from a bioassay measurement by assuming exposure to HTO. The exception is for workers in Building 331 that housed research and laboratory operations, where isotopic ratios for HTO, HT and elemental tritium are given (see Table 5-1). An OTIB addressing the assessment of metal tritides is scheduled for development.*
>
> *As far as OBT is concerned, there a couple of competing processes going on:*
>
> 1) *The method we use to evaluate tritium urine bioassay data tends to overestimate the dose from HTO a bit and underestimate the dose from OBT a bit.*
> 2) *OBT tends to be less common in the workplace and when it does occur it tends to be less volatile than HTO, which translates into less potential for exposure to OBT in production environments.*
> 3) *OBT tends to occur with HTO rather than by itself, which on the average substantially reduces any potential underestimates of doses from OBT intakes.*
>
> *Based on these considerations, it is felt that OBTs in the workplace do not warrant special treatment or consideration.*

(6) Will NIOSH determine if there was potential for exposure to high-fired plutonium oxides and how will the internal dose assessment for these be handled if this occurred (will NIOSH modify any biokinetic models to assess this accurately)?

> ***Response:*** *Assumption of absorption types is considered a generic dose reconstruction issue. The TBD identifies the radioactive materials and associated processes, so appropriate absorption types can be determined and applied by dose reconstructors. An OTIB addressing the assessment of very insoluble ("super S") plutonium is currently at OCAS for review.*

(7) NIOSH lists several aging states of weapons grade plutonium that were handled at LLNL. How will NIOSH decide on which aging mixture of plutonium isotopes will be used for data interpretation and intake assessment?

> ***Response:*** *The americium-plutonium (Am-Pu) ratio noted in in vivo bioassay results should be compared to the values listed in Table 5-2 of the TBD in order to assess the age of the mixture. For in vitro bioassay results, the ratio of plutonium isotopes (from alpha spectroscopy) is compared to the Table 5-2*

values. A default value of 10 yr aged Pu is used in DR. This default value is used unless an actual value can be discerned from claimant specific data.

(8) NIOSH states, "Other variables, such as particle sizes and clearance classes can be readily reconstructed from historical records." No further discussion is found on the specific clearance classes that were involved with radionuclide intakes at the site. Is NIOSH going to publish a list of the clearance classes of radionuclide compounds used at the site and associate these with specific buildings or projects? Is NIOSH going to investigate if there is any site-specific airborne radionuclide particle size analysis data available (determination of actual activity median aerodynamic diameters)? Some sites have been known to perform particle size analysis with impactors or other analytical equipment. Some sites have also done solubility analysis of radionuclide compounds it handled to determine actual clearance classes and rates.

Response: *At this point in time, this information is not available to us. The claimant records typically lack enough detail to identify one specific work location for an individual, and the materials used in a location often change over time making it difficult to assign one particle size and one material type to an are, so default (for particle size) or claimant favorable (for material type) assumptions would most likely be used for the majority of cases even if there were building-specific information.*

(9) NIOSH does not identify any use of chelation treatments or any other radionuclide intake medical intervention in the TBD (as the LANL internal dose TBD identified). This infers that there were no major radionuclide intakes requiring medical intervention in the history of the site. Does NIOSH plan to investigate this further? How will NIOSH handle dose reconstruction for any workers that had medical intervention treatments for minimizing internal dose?

Response: *Because the administration of DTPA was required to be reported to a central authority, it is assumed that records were kept in the individual files. Dose assessments for chelated claimants will be handled by the dose reconstructors on a case-by-case basis.*

(10) As noted in the LANL internal dose TBD, intakes that occurred many years earlier that were not detectable with past bioassay methods can become detectable several years after the intake due to the improvement of the bioassay methods (lowered MDAs/MDCs). Two of the difficulties with estimating the intakes from new positive bioassay data that may be identifying an intake that was undetected for many years are assumptions for intake date(s) and intake radionuclide composition. Does NIOSH have an approach identified on how to reconstruct internal doses in these situations?

Response: *While there are standard practices for assessing individuals with no results exceeding the detection level, positive results are handled on a case-by-case basis. In general, the appearance of a positive result following a series of negative results would tend to indicate an acute intake and the starting* *assumption would be to assume an intake occurred at the midpoint between the date of the positive result and the previous result. However, all data would be reviewed, including the change in MDAs over time, subsequent sample results, and results from other bioassay methods to ensure that they were consistent.*

(11) NIOSH states that, "Air Monitoring in workplaces and in the breathing zones of employees has been a common surveillance method" at LLNL. No specific air sampling data, use and evolution of applied air concentration limits/action levels, or use of respiratory protection are discussed which would give information on the radionuclide air concentrations that workers could have been exposed to (as opposed to the discussion in the LANL internal dose TBD). Has NIOSH reviewed any of this LLNL data and respiratory protection program information to determine if it has any usefulness in the internal dose reconstruction effort?

Response: *This information is currently not used when performing a dose reconstruction. This has not yet been addressed; it will be reviewed. If additional information becomes available and if it indicates modifications are warranted, information will be added to the TBD for use by dose reconstructors.*

(12) The incident table (Table 5-7) has very few incidents. Does NIOSH plan to do a thorough search of the incident information available for LLNL in order to identify as many incidents with internal dose significance as possible to assist the dose reconstructors? Incident reports often provide very useful information for accurate dose reconstruction.

Response: *Section 5.4 of the TBD acknowledges that many other incidents other than those listed in Table 5-7 may have occurred. As they are identified, they will be captured in future revisions of the TBD.*

(13) Has NIOSH reviewed any contamination monitoring that may have been done in areas around the perimeter of airborne and surface contamination areas to determine if workers in these perimeter areas may have had intakes?

Response: *This issue is addressed in LLNL-4.*

(14) Has NIOSH determined if there was any specific monitoring performed for LLNL personnel that were exposed during work at other sites such as Nevada Test Site, Pacific proving grounds, etc.? If these personnel were monitored by the bioassay program at the other site will NIOSH be able to retrieve that data for dose reconstruction?

Response: *Visitor data requests are made when there is evidence that an individual performed work at another site. Many LLNL claims contain visitor data from NTS (although it's typically external rather than internal data).*

(15) How does NIOSH plan to handle the identification of radionuclides intakes associated with the bioassays identified in Table 5-4 that have "Not Specified" in the radionuclide identification column (i.e., radionuclide the bioassay was for is unknown)?

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Response: *The reference(s) used to prepare those entries indicated that bioassays had been performed during the time periods in question, but no specifics on what samples were analyzed for were given. It is presumed the dose reconstructors will use the isotope-specific analytical results that appear in the bioassay records of that vintage for the individuals in question for the dose assessments.*

Within the claimant specific records, it is common for the radionuclide to be unknown. This is the case for gross alpha, beta and MFP bioassays which were performed at LLNL and appear in the claimant records. When this occurs, the dose reconstruction for that individual would be performed as elsewhere described in the TBD (i.e., Section 5.3.3).

(16) Some buildings at LLNL had "source terms" with dozens of radionuclides identified in Attachment A. Some of these radionuclides have activity fractions that are very small (e.g., ^{229}Th = 2.2E-12 in Building 132). Does NIOSH plan to assign an intake of all radionuclides listed in Attachment A shown for the applicable building that is involved in an intake assessment or is there going to be a threshold activity fraction below which radionuclides will not be included

Response: *The source term data is made available in order to assist the DR in the determination of exposure potential when specific data is not available. The data in these tables applies only to post 1993, and its use has been clarified in the revision to the TBD.*

(17) ^{226}Ra and ^{228}Ra are shown as radionuclides in several of the waste processing and storage buildings (513, 514, 612, and 625) in Table 2-2 of the Site Description TBD and at fairly significant fractions of the activity in the 514 Tank Farm (1.55E-4 for ^{226}Ra). Has NIOSH determined if there were/are any projects that could have caused significant radon and/or thoron exposures?

Response: *This has not yet been addressed; it will be reviewed.*

Occupational External Dose (ORAUT-TKBS-0035-6)

(1) On Page 6 of the LLNL Occupational External Dose TBD (Szalinski 2005), it is stated that personnel dosimeter records are generally available for all periods, and they are of the highest quality. However, during a recent search in the DOE records, only the ***total*** dose for all the years in the 1960s, 1970s, and into the 1980s was found for each of the radiation types (photon, electron, and neutron). No yearly (or quarterly) dose data records were found during a period when all workers were to be monitored (i.e., all years were after 1958) and data for each exchange period should have been available. Shouldn't dose records for each exchange period be available to the dose reconstructor?

Response: *Dose records and periods of monitoring are provided in the NOCTS Claim Record documents.*

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During the conversion to electronic recordkeeping, only positive dosimeter values were populated. As a result, prior to 1980, there are only records of non-zero individual dosimeter results.

(2) On page 6, Section 6.3 (Szalinski 2005), it is stated that dose reconstructors can compare earlier dosimetry systems to current systems to evaluate their performances. While this may be a possibility, considering the number of cases handled, this most likely would not occur during the dose reconstruction process. Could more specific examples be included in the TBD to expand on this concept and assist the dose reconstructor?

Response: *There are documented historical studies of dosimeter performance as noted in the following:*

1. *AEC (U.S. Atomic Energy Commission), 1955, "Intercomparison of Film Badge Interpretations," Isotopics, Volume 2, number 5, pp. 8–23.*
2. *Brackenbush, L.W., G.W.R. Endres, J. M. Selby, and E.J. Vallario. 1980. Personnel Neutron Dosimetry at Department of Energy Facilities. PNL-3213. Pacific Northwest Laboratory, Richland, WA 99352.*
3. *Brackenbush, L.W., K.L. Soldat, D. L. Haggard, L. G. Faust and P. L. Tomeraasen. 1987. Neutron Dose and Energy Spectra Measurements at Savannah River Plant. PNL-6301. Pacific Northwest Laboratory, Richland, WA 99352.*
4. *Brodsky, A., and R.L. Kathren, 1963, Accuracy and Sensitivity of Film Measurements of Gamma Radiation –Part I: Comparison of Multiple-Film and Single-Quarterly-Film Measurements of Gamma Dose at Several Environmental Conditions, Health Phys 9(4):453-461.*
5. *Brodsky, A., and R.L. Kathren, 1963, Accuracy and Sensitivity of Film Measurements of Gamma Radiation –Part II: Limits of Sensitivity and Precision, Health Phys 9(5):463-471.*
6. *Brodsky, A., A.A. Spritzer, F.E. Feagin, F.J. Bradley, G. Karches and H.I. Mandelberg, 1963, Accuracy and Sensitivity of Film Measurements of Gamma Radiation –Part IV: Intrinsic and Extrinsic Errors, Health Phys 11(10):1071-1082.*
7. *Gorson, R.O., N. Suntharalingam, and J.W. Thomas, 1963, Results of a Film-Badge Reliability Study, Presented at the 49th Annual Meeting of the Radiological Society of North America, Chicago, IL, Nov. 17–22, 1963.*
8. *Morgan, K. Z., 1961, "Dosimetry Requirements for Protection from Ionizing Radiation," Selected Topics in Radiation Dosimetry, Proceedings of the Symposium on Selected Topics in Radiation Dosimetry, Sponsored by and Held in Vienna 7–11 June 1960, International Atomic Energy Agency, Vienna, Austria, pp. 3–23.*
9. *Parker, H. M, 1945, Comparison of Badge Film Readings at the Metallurgical Laboratories, Clinton Laboratories and the Hanford Engineering Works, 7-3090, Hanford Atomic Products Operation, Richland, Washington. (SRS used Clinton dosimetry services and then implemented systems similar to other laboratories)*

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10. *Plato, P., 1978, Testing and Evaluating Personal Dosimetry Services in 1976, Health Phys 34(3):219-223.*
11. *Thierry-Chef, I., F. Pernicka, M. Marshall, E. Cardis and P. Andreo. 2002. Study of a Selection of 10 Historical Types of Dosimeter: Variation of the Response to Hp(10) with Photon Energy and Geometry of Exposure. Radiat Prot Dos, 102(2): 101-113. (Includes SRS Panasonic 802 dosimeter)*
12. *Vallario, E. J, D.E. Hankins and C.M. Unruh. 1969. AEC Workshop on Personnel Neutron Dosimetry. BNWL-1340. Battelle, Pacific Northwest Laboratory, Richland, WA.*
13. *Vallario, EJ, D.E. Hankins and C.M. Unruh. 1971. Second AEC Workshop on Personnel Neutron Dosimetry. BNWL-1616. Battelle, Pacific Northwest Laboratory, Richland, WA.*
14. *Wilson, R.H., J.J. Fix, W. V. Baumgartner, and L. L. Nichols. 1990. Description and Evaluation of the Hanford Personnel Dosimeter Program From 1944 Through 1989. PNL-7447. Pacific Northwest Laboratory, Richland, WA (see section 5.3 on intercomparison programs).*

The circumstances of these dosimeter performance studies are compared to the LLNL workplace radiation fields to arrive at an estimated level of accuracy. Instructions are provided in ORAUT-TKBS-0035-6 section 6.4 on adjustments to recorded dose. These instructions are provided to ensure the dose reconstruction is claimant favorable and the limitations of the dosimetry and practices of the monitoring period are adjusted to the standards outlined in OCAS-IG-001, External Dose Reconstruction Implementation Guideline.

(3) On Page 7, Section 6.3 (Szalinski 2005), it is mentioned that the original dose data combined with detailed examinations of workplace radiation fields can be used to provide the best estimate of the worker's dose. It does not appear that there is a lot of detailed information in this TBD, other than energy intervals, concerning the many different radiation fields (such as the percent of neutrons below the threshold of the NTA film, dosimetry response to different exposure geometries and different mixed radiation fields, etc.) for the dose reconstructor to refer to. Plus, most dose reconstructors do not have time to analyze each case to that level of detail, unless these adjustments are specifically spelled out in the TBDs. Could more radiation field details for various locations and time periods at LLNL be provided in the TBD in summary tables to assist the dose reconstructor to make more reliable dose assignments when concerned with different radiation fields?

Response: *Information about the individual worker's unique exposure conditions would be obtained during the Computerized Assisted Telephone Interviews (CATIs). If the individual's dosimetry records are determined by the DR to be inadequate for dose reconstruction, then additional information may be obtained from site records as described in OCAS-IG-001, External Dose Reconstruction Implementation Guideline, Sections 1.1.2 Not Monitored and 1.1.3 Monitored Inadequately.*

(4) Table 6-1 on page 7 (Szalinski 2005) provides a list of MDL (in rem) for different types of dosimeters for different time periods. The MDLs for neutron dosimeters remain constant for a given type and time period regardless of the exchange frequency (i.e., 0.050 rem regardless of the exchange period). However, the MDL for a given photon/electron dosimeter, and given time period, changes with exchange frequency (i.e., 0.015 rem for weekly, 0.020 rem for Biweekly, and 0.030 rem for Monthly exchanges). The MDL is an inherit property of the dosimeter that should be independent of the use period (especially in this case because no background control dose was subtracted from the readings according to Page 15 of the TBD). Would you please explain the reason for the changes in the MDL as a function of exchange frequency?

Response: *The MDLs provided will provide claimant favorable results in that they overestimate the fade of the film badge exchange frequencies of biweekly and monthly. The MDLs are reported as they were obtained from LLNL records. The differences in MDL with measurement periods is presumed to be a function of fading of the radiation induced signal which becomes more significant with longer exchange periods.*

(5) Section 6.3.1 on Page 8 (and also Table 6-5 on page 12) (Szalinski 2005) states that LLNL has always had the policy of monitoring individuals with any significant potential for exposure and has monitored all workers entering the site since May 1958. This brings up several questions:

a. What defined "significant potential" for badging prior to May 1958?
b. How was it decided to monitor or not monitor workers for neutrons along with photon/betas before 1958 (i.e., any further details concerning significant potential for neutron exposures)?
c. Were all workers who entered the site badged for neutrons as well as photon/beta after May 1958?
d. Were all neutron and photon/beta monitoring badges read at all times AND recorded in the dose records?
e. Has the same badging policies applied to Site 300, as they were for the LLNL main site?
f. Does monitoring of all workers entering the site include subcontractor, D&D, construction workers, and rovers from May 1958 to present? Was neutron monitoring always included for these workers, or was it on an as needed basis?

Response:

(a) Prior to 1958, personnel monitoring procedures required all persons entering a radiation area to wear a film badge (Block 1954). Records dating back to February 1953 required personnel whose daily work "might" expose them to ionizing radiation of any kind to wear a film badge, and with few exceptions film badges were available for each employee at Livermore (Nolan 1953). This is further verified by available records showing that 125,000 film badges (for weekly badge changes) were ordered for 1956–1957 (Wilcox 1956).

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(b) The criteria for neutron monitoring were not found. As described in Section 6.3.2.2 of the ORAUT-TKBS-0035-6, "no definition of 'significant' was provided. It is reasonable to consider significant to be some fraction of the applicable radiation safety standards. At this time there are no clear criteria for how neutron dosimeters were assigned. If available, coworker data should be used."

(c) See response to (b).

(d) It is presumed that neutron and photon/beta badges worn by employees were read at all times. See section 6.3.2 of ORAUT-TKBS-0035-6.

(e) Yes, documents reviewed showed that the same badging policies applied to site 300 (Lindeken 1956).

(f) Yes, documentation shows that all contractors, and outside consultants were classified as visitors and were monitored by film badges (Block 1954, Block 1954 b, Nolan 1956). To answer the question about neutron badging, in a discussion between Paul Szalinski and Ron Kathren (8/14/2006)[1], Mr. Kathren indicated that approximately 10% of the workers were issued NTA and that it is reasonable to assume people who were issued NTA film were the ones who were exposed.

The following is a list of references used in the above responses for question 5:

1. *Block 1954, Personnel Monitoring Procedure for UCRL, Livermore, Memorandum from S. Block to All Department Heads, July 19. [SRDB Ref ID: 15708].*
2. *Block 1954b, Visitor's Film Badges, Memorandum from Seymour Block to Robert Becker, November 19. [SRDB Ref ID: 15707].*
3. *Nolan 1953, Film Badge and Pocket Dosimeter Information, Memorandum from W. E. Nolan, to All Livermore Employees, February 5. [SRDB Ref ID: 15715].*
4. *Nolan 1956, Film Badge Coverage for P.T.I., Memorandum from W. E. Nolan, to C. L. Blue, December 19. [SRDB Ref ID: 15754].*
5. *Lindeken 1956, Film Badge Coverage at Site 300, Memorandum from C.L. Lindeken to G. E. Wilcox, March 11. [SRDB Ref ID: 15703].*
6. *Wilcox 1956, New Film -555 For 1956–1957, Memorandum from G. E. Wilcox, to W. E. Nolan and S. Block, March 19. [SRDB Ref ID: 15705].[2]*

(6) Table 6-5 on page 12 (Szalinski 2005) provides an interpretation of reported data. Several questions concerning this table are listed below:

[1] Paul Szalinski and Ron Kathren are currently a part of the NIOSH/ORAU Team.
[2] The six documents listed here by NIOSH are LLNL internal memoranda. All authors and recipients were LLNL employees.

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a. In the "Interpretation of blanks (no data)" column, it states that, "No data or blanks should be interpreted as individual was monitored with zero results." How can it be stated that a worker was monitored, and the results were zero when a blank could mean a worker was not monitored, badge was lost, not returned, or not read?
b. In the "Monitored/unmonitored" column, it states that, "(more than 95% of employees were monitored before 1958)." Is there any details concerning the percent of workers monitored each year, percent monitored for neutrons, and monitored workers' location information for each year for 1952–1957?

Response:

(a) Individual claim records for LLNL in the NOCTS data base showed that when a badge was lost or not returned the word "missing" was entered onto the dosimetry record. The assumption that the individual was monitored but the results were zero (as apposed to the individual was not monitored and away from the jobsite) is claimant favorable because the DR will assign a missed dose equivalent to ½ the MDL in accordance with OCAS-IG-001, External Dose Reconstruction Implementation Guideline. It was also noted in the NOCTS records that the "Request for Personnel Exposure Under the EEOICPA" was summarized and interpreted and signed by the LLNL dosimetrist and an interpretation of the blanks in the historical records would not be required by the DR.

(b) The guidance documents note that all employees who might be exposed to ionizing radiation wear a film badge. See response to 5(a) above. In addition, visitors to the site were also monitored using film badges. There are no additional details identified at this time concerning the percent of workers monitored each year, percent monitored for neutrons, and monitored workers' location information for each year for 1952–1957

(7) Table 6-7, Page 14 (Szalinski 2005), list "*Bias and uncertainty*" for the dosimetry system. It lists a range of bias for different dosimetry systems. In the text on page 14 it recommends that the dose reconstructor use an uncertainty factor of 1.2.

a. Is it intended that the dose reconstructor is not to use the values in Table 6-7, but always use the 1.2 value?

b. OCAS-IG-001 (NIOSH 2002), Section 2.1.1.4 Page 16, indicates that the laboratory uncertainty was not less than 1.2. When factoring in environmental affects (heat, humidity, processing, etc.) and exposure uncertainties (different energies, geometry, etc.) the overall uncertainty would most likely be greater than 1.2. How can an uncertainty of 1.2 be considered claimant favorable for both film and TLDs when this is a minimum value for lab uncertainty only?

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Response:

(a) Yes, the text on page 14 describes that DRs should use an uncertainty factor of 1.2.

(b) As described in OCAS-IG-001 (NIOSH 2002), Section 2.1.1.3 Page 13 describes …"for simplicity, the approach outlined by the National Research Council (1989) will be employed for dose reconstruction under EEOICPA. However, the additional uncertainty discussed for exposures below 200 mR will not be employed, since routine monitoring is generally more precise than large sampling events…" Figure 2.1 of OCAS-IG-001 shows that above 200 mR the 95% uncertainty factor K(E) is approximately 1.2. Use of this factor to calculate the upper 95% confidence dose is claimant favorable.

(8) Section 6.7, Page 14 (Szalinski 2005), recommends that the dose reconstructor use coworker data and population data to assign doses to unmonitored workers. Coworker and population data does not appear to be present in the current TBD. Also, CATI reports generally do not contain sufficient information to acquire this type of data, and it would be too time consuming to create a coworker dose model for each worker. Where/when will this coworker/population dose data be available for the dose reconstructor to use?

Response: *Coworker data is used when there is insufficient monitoring data for the claimant. As described in OCAS-IG-001, Section 3.1.1, and 3.2.1, a list of coworkers could be identified. One option may be to examine the records for other LLNL EE claims that contain doses for monitored workers. The basis to prepare a coworker database for LLNL is under examination.*

(9) Section 6.7, Page 14 (Szalinski 2005), states that, "For unmonitored workers whose exposure potential has been determined to be low, assign the environmental dose." Is this decision left solely up to the individual dose reconstructor, or are there any guidelines (which consider work locations and time periods specific to the LLNL site) available to the dose reconstructor?

Response: *The decision is left up to the DR following guidance contained in OCAS-IG-001. However, it is noted that most individuals at the LLNL site, including visitors, were monitored with a film badge. The respective dose reconstructions are subject to internal ORAUT, OCAS and DOL review.*

The DR takes into account information contained in the individual claimant records (CATI, dosimetry records) as well as the TBD in making this determination.

(10) Sections 6.3.3 and 6.3.4 along with Table 6-3, Page 11 (Szalinski 2005), mentions neutron dosimetry and assigns an energy interval of 0.1–2.0 MeV 100% of the time. However, other information is lacking concerning details of neutron fields and dosimetry. Some areas of concern are:

a. At an energy interval of 0.1–2.0 MeV, NTA film (used 1952–1969) would miss most of the doses below about 700 keV.
   i. When was the inadequacy of NTA film for lower energy neutrons recognized at LLNL?
   ii. How was it addressed?
   iii. Were there areas at LLNL where a significant portion of the neutron dose consisted of neutrons less than 700 keV?
   iv. Were the worker's recorded neutron doses corrected, or do they presently need to be corrected, to assign the correct neutron dose?
   v. How is this going to be accounted for in the dose reconstruction?

Response: *Inadequacy of NTA film was recognized in the early 1950's. The technical challenges were evident and the result of numerous studies and publications (Cheka 1954 and Kathren 1964). In addition 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 in 1969 (Vallario1969) concluded that "… for intermediate energy (>0.4 ev to < 700 keV)… neutron sources, NTA personnel neutron dosimeters cannot be effectively used…"*

The DR is instructed to assess the potential missed neutron dose using a neutron to photon dose ratio as described in Section 2.2.1 of OCAS-IG-001.

The following is a list of references used in the above responses for question 10a:

1. *Cheka 1954, Recent Developments in Film Monitoring of Fast Neutrons, Joseph S. Cheka, NUCLEONICS, Vol. 12, No. 6 June.*
2. *Kathren, R.L., C.T. Prevo, and S. Block, 1964, Angular Dependence of Eastman Type A (NTA) Personnel Monitoring Film, UCRL-12199, Earnest O. Lawrence Radiation Laboratory, University of California, Livermore, California.*
3. *Vallario, E.J., D.E. Hankins, and C. M. Unruh, 1969, AEC Workshop on Personnel Neutron Dosimeter, BNWL-1340, Pacific Northwest Laboratory, Richland Washington.*

b. Section 6.3.3.2, Page 9 (Szalinski 2005), states that PuBe sources were used prior to 1970 to calibrate neutron dosimeters. How is this sufficient to cover the large neutron energy range at LLNL to include low-energy neutron fields at critical assemblies and reactors to high-energy accelerators with widely varying neutron energies and shielding arrangements?

   Response: *In the 1960s LLNL created a set of DO spheres to moderate the PuBe energy for calibration (8/14/2006 teleconference between R. Kathren and P. Szalinski).*

c. Were different calibration factors used for different work areas (i.e., different neutron fields) when PuBe sources were used for calibration?

Response: *No documentation was found to indicate that different calibration factors were used for different work areas.*

(11) Table 6-7, Page 14 (Szalinski 2005), shows that TLDs were used to monitor neutron doses 1969–present. During 1969–1986, how were the higher energy neutrons (such as around the numerous accelerator at LLNL) monitored? Was NTA film used in conjunction with TLDs?

Response: *The table and research indicates that only TLDs were used after 1969.*

(12) Could you please elaborate concerning where CR-39 dosimetry has been used since 1986 and how this is integrated into the overall total neutron dose recorded for a worker at LLNL in conjunction with the TLD readings?

Response: *CR59 etch track dosimetry is used in facilities where employees work with neutron generators or linear accelerator cyclotrons. Neutron and photon dose are recorded separately and summed to obtain the Hp(10).*

(13) Section 6.3.3.2, Page 9 (Szalinski 2005), states that since 1970 unmoderated and moderated Cf-252 sources have been used to calibrate neutron dosimeters. Does this apply to all areas (reactors to accelerators) for all TLDs and CR-39 dosimeters? Is there differ calibration factors for different location (i.e., neutron energy fields) at LLNL?

Response: *No documentation was found to indicate that different calibration factors were used for different work areas. CR-39 has the advantage of a comparatively plat dose equivalent response with neutron energy. Follow-up discussions with LLNL employees may provide additional information.*

Final Questions on the Internal Dose TBD submitted to NIOSH on June 8, 2007 and received from NIOSH/ORAU on June 29, 2007 (Not Discussed during a Conference Call)

(1) Has NIOSH determined how they are going to interpret gross alpha, gross beta, and MFP in-vitro bioassay results? Will any doses be assessed using these bioassay data and how will it be done?

Answer: *The current revision to the TBD, ORAUT-TKBS-0035-5, Rev. 01, contains guidance on the interpretation of gross alpha, gross beta, and fission product bioassay results. This interpretation of the results is how the dose reconstructors will use them for assessments.*

(2) Has NIOSH investigated further the potential for exposure to special tritium compounds (metal tritides and organically bound tritium) and what are the results of the investigation?

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Answer: *If indicated in an employee's file, metal tritides and organically bound tritium are addressed through the use of ORAUT-OTIB-0066, "Calculation of Dose from Intakes of Special Tritium Compounds." Metal tritides and organically bound tritium were used at LLNL, but in very small quantities compared to tritium gas (HT).*
This may be a partial response. We may find more on this in the review of the new documents.

(3) Has NIOSH found any further information on the chemical forms of radionuclides handled to give further information for the dose reconstructors?

Answer: *Having the chemical forms of the radionuclides handled at LLNL is useful information, and we prefer to have it. However, it is not necessary to have the information because dose reconstructors assign the material type yielding the largest dose if it is unknown.*

(4) Has NIOSH found any significant sources of radon and thoron that need to be accounted for in the internal dose reconstruction and how will these be assessed?

Answer: *No mention of significant exposures to radon or thoron was found during site research.*

This may be a partial response. We may find more on this in the review of the new documents.

(5) Has NIOSH found any new information on the MDAs and MDCs for bioassays and will the TBD be updated with this?

Answer: *The TBD contains a list of bioassay analyses and corresponding MDAs for most methods; however, this list is based on ICRP and ANSI documentation and is not LLNL-specific. As additional MDAs or MDCs are identified, the TBD will be updated.*

This may be a partial response, at least as far as whole body counting goes. We may find more on this in the review of the new documents.

(6) Has NIOSH determined a default uranium type for the dose assessment from in-vitro bioassay mass concentration (μg/liter) data and what is it (depleted, natural, or enriched at some percent)? If NIOSH will not identify a default type how will internal dosimetrists choose the correct type?

Answer: *The TBD has identified the default type to be natural U. (This has recently been corrected in a revision/page change to ORAUT-TKBS-0035-5, Rev. 01.)*

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(7) From the site interviews it was determined that thorium was handled frequently especially in the earlier years, how will the dose from this be assessed?

> ***Answer:*** *Guidance has been provided in the TBD revision on how to evaluate thorium from whole body count and gross alpha urinalysis data for the post-1970 years. This guidance is discussed on page 13 of the TBD revision:*
>
> > *"Another possible exception would involve thorium. LLNL performed some machining of thorium. Indications are that whole body counting was used to monitor for thorium intakes. If a worker was getting regular uranium analyses, then had a gross alpha bioassay analysis, this suggests that the worker had been working with the uncontained thorium, and the gross alpha result should be interpreted as thorium. The worker's job description should be evaluated to determine if this is appropriate. If there is a whole body count, then the thorium intake calculated from the gross alpha urinalysis could be compared against the detection limit of the whole body count."*
>
> *Also, an 83.14 SEC has been proposed for the early years at LLNL (through 1973).*
>
> *This may be a partial response. We may find more on this in the review of the new documents.*

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REFERENCES

ORAUT-TKBS-0035-1, *Lawrence Livermore National Laboratory l – Introduction*, Rev. 00 PC-1 (Maisler 2005) September 12, 2005.

ORAUT-TKBS-0035-2, *Lawrence Livermore National Laboratory – Site Description*, Rev. 00 PC-1 (Maisler 2005) October 26, 2005

ORAUT-TKBS-0035-3, *Lawrence Livermore National Laboratory – Occupational Medical Dose*, Rev. 00 PC-1 (Turner 2005) October 26, 2005.

ORAUT-TKBS-0035-4, *Lawrence Livermore National Laboratory – Occupational Environmental Dose*, Rev. 00 PC-1 (Thomas 2005) November 18, 2005

ORAUT-TKBS-0035-5, *Lawrence Livermore National Laboratory – Occupational Internal Dose*, Rev 00 (Berger and Szalinski 2005) October 10, 2005

ORAUT-TKBS-0035-6, *Lawrence Livermore National Laboratory – Occupational External Dose*, Rev. 00 (Szalinski 2005) October 7, 2005

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

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ATTACHMENT 4: LLNL-SPONSORED ATMOSPHERIC AND UNDERWATER TESTING

Table A6-1: Lawrence Livermore National Laboratory-Sponsored Atmospheric Weapons Tests, Underwater Weapons Tests, and Special Projects

Source: DOE 2000

Test Name	Operation	Date	Location	Type	Purpose
Ruth	Upshot-Knothole	03/31/1953	NTS	Tower	Weapons Related
Ray	Upshot-Knothole	04/11/1953	NTS	Tower	Weapons Related
Simon	Upshot-Knothole	04/25/1953	NTS	Tower	Weapons Related
Koon	Castle	04/06/1954	Bikini Island	Surface	Weapons Related
Tesla	Teapot	03/01/1955	NTS	Tower	Weapons Related
Turk	Teapot	03/07/1955	NTS	Tower	Weapons Related
Post	Teapot	04/09/1955	NTS	Tower	Weapons Related
Zuni	Redwing	05/27/1956	Bikini Island	Surface	Weapons Related
Yuma	Redwing	05/27/1956	Enewetak	Tower	Weapons Related
Kickapoo	Redwing	06/13/1956	Enewetak	Tower	Weapons Related
Inca	Redwing	06/25/1956	Enewetak	Tower	Weapons Related
Mohawk	Redwing	07/02/1956	Enewetak	Tower	Weapons Related
Apache	Redwing	07/08/1956	Enewetak	Barge	Weapons Related
Tewa	Redwing	07/20/1956	Bikini Island	Barge	Weapons Related
Lassen	Plumbbob	06/05/1957	NTS	Balloon	Weapons Related
Wilson	Plumbbob	06/18/1957	NTS	Balloon	Weapons Related
Hood	Plumbbob	07/05/1957	NTS	Balloon	Weapons Related
Diablo	Plumbbob	07/15/1957	NTS	Tower	Weapons Related
Owens	Plumbbob	07/25/1957	NTS	Balloon	Weapons Related
Saturn	Plumbbob	08/10/1957	NTS	Tunnel	Safety Experiment
Shasta	Plumbbob	08/18/1957	NTS	Tower	Weapons Related
Smoky	Plumbbob	08/31/1957	NTS	Tower	Weapons Related
Wheeler	Plumbbob	09/06/1957	NTS	Balloon	Weapons Related
Rainier	Plumbbob	09/19/1957	NTS	Tunnel	Weapons Related
Whitney	Plumbbob	09/23/1957	NTS	Tower	Weapons Related
Charleston	Plumbbob	09/28/1957	NTS	Balloon	Weapons Related
Morgan	Plumbbob	10/07/1957	NTS	Balloon	Weapons Related
Venus	Project 58 A	02/22/1958	NTS	Tunnel	Safety Experiment
Uranus	Project 58 A	03/14/1958	NTS	Tunnel	Safety Experiment
Fir	Hardtack 1	05/11/1958	Bikini Island	Barge	Weapons Related
Nutmeg	Hardtack 1	05/21/1958	Enewetak	Barge	Weapons Related
Sycamore	Hardtack 1	05/31/1958	Bikini Island	Barge	Weapons Related
Maple	Hardtack 1	06/10/1958	Bikini Island	Barge	Weapons Related
Aspen	Hardtack 1	06/14/1958	Bikini Island	Barge	Weapons Related
Redwood	Hardtack 1	06/27/1958	Bikini Island	Barge	Weapons Related
Hickory	Hardtack 1	06/29/1958	Bikini Island	Barge	Weapons Related
Cedar	Hardtack 1	07/02/1958	Bikini Island	Barge	Weapons Related
Dogwood	Hardtack 1	07/05/1958	Enewetak	Barge	Weapons Related
Poplar	Hardtack 1	07/12/1958	Bikini Island	Barge	Weapons Related

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Table A6-1: Lawrence Livermore National Laboratory-Sponsored Atmospheric Weapons Tests, Underwater Weapons Tests, and Special Projects

Source: DOE 2000

Test Name	Operation	Date	Location	Type	Purpose
Juniper	Hardtack 1	07/22/1958	Bikini Island	Barge	Weapons Related
Olive	Hardtack 1	07/22/1958	Enewetak	Barge	Weapons Related
Pine	Hardtack 1	07/26/1958	Enewetak	Barge	Weapons Related
Quince	Hardtack 1	08/06/1958	Enewetak	Surface	Weapons Related
Fig	Hardtack 1	08/18/1958	Enewetak	Surface	Weapons Related
Mercury	Hardtack II	09/23/1958	NTS	Tunnel	Safety Experiment
Mars	Hardtack II	09/28/1958	NTS	Tunnel	Safety Experiment
Colfax	Hardtack II	10/05/1958	NTS	Shaft	Safety Experiment
Tamalpais	Hardtack II	10/08/1958	NTS	Tunnel	Weapons Related
Neptune	Hardtack II	10/14/1958	NTS	Tunnel	Safety Experiment
Hamilton	Hardtack II	10/15/1958	NTS	Tower	Weapons Related
Logan	Hardtack II	10/16/1958	NTS	Tunnel	Weapons Related
Vesta	Hardtack II	10/17/1958	NTS	Surface	Safety Experiment
Wrangell	Hardtack II	10/22/1958	NTS	Balloon	Weapons Related
Rushmore	Hardtack II	10/22/1958	NTS	Balloon	Weapons Related
Juno	Hardtack II	10/24/1958	NTS	Surface	Safety Experiment
Ceres	Hardtack II	10/26/1958	NTS	Tower	Safety Experiment
Sanford	Hardtack II	10/26/1958	NTS	Balloon	Weapons Related
Evans	Hardtack II	10/29/1958	NTS	Tunnel	Weapons Related
Humboldt	Hardtack II	10/29/1958	NTS	Tower	Weapons Related
Mazama	Hardtack II	10/29/1958	NTS	Tower	Weapons Related
Blanca	Hardtack II	10/30/1958	NTS	Tunnel	Weapons Related
Ganymede	Hardtack II	10/30/1958	NTS	Surface	Safety Experiment
Titania	Hardtack II	10/30/1958	NTS	Tower	Safety Experiment
Antler	Nougat	09/15/1961	NTS	Tunnel	Weapons Related
Chena	Nougat	10/10/1961	NTS	Tunnel	Weapons Related
Gnome	Nougat	12/10/1961	NTS	Shaft	Plowshare
Mad	Nougat	12/13/1961	NTS	Shaft	Weapons Related
Feather	Nougat	12/22/1961	NTS	Tunnel	Weapons Related
Stillwater	Nougat	02/08/1962	NTS	Shaft	Weapons Related
Codsaw	Nougat	02/19/1962	NTS	Shaft	Weapons Related
Cimarron	Nougat	02/23/1962	NTS	Shaft	Weapons Related
Danny Boy	Nougat	03/01/1962	NTS	Crater	Weapons Effects
Brazos	Nougat	03/15/1962	NTS	Shaft	Weapons Effects
Hoosic	Nougat	03/28/1962	NTS	Shaft	Weapons Effects
Passaic	Nougat	04/06/1962	NTS	Shaft	Weapons Effects
Hudson	Nougat	04/12/1962	NTS	Shaft	Weapons Related
Platte	Nougat	04/14/1962	NTS	Tunnel	Weapons Related
Dead	Nougat	04/21/1962	NTS	Shaft	Weapons Related
Black	Nougat	04/27/1962	NTS	Shaft	Weapons Related
Arkansas	Nougat	05/02/1962	Christmas Island Area	Airdrop	Weapons Related
Frigate Bird	Nougat	05/06/1962	Pacific	Rocket	Weapons Related

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Table A6-1: Lawrence Livermore National Laboratory-Sponsored Atmospheric Weapons Tests, Underwater Weapons Tests, and Special Projects

Source: DOE 2000

Test Name	Operation	Date	Location	Type	Purpose
Yukon	Nougat	05/07/1962	Christmas Island Area	Airdrop	Weapons Related
Arikaree	Nougat	05/10/1962	NTS	Shaft	Weapons Related
Muskegon	Nougat	05/11/1962	Christmas Island Area	Airdrop	Weapons Related
Swanee	Nougat	05/14/1962	Christmas Island Area	Airdrop	Weapons Related
Eel	Nougat	05/19/1962	NTS	Shaft	Weapons Related
Chetco	Nougat	05/19/1962	Christmas Island Area	Airdrop	Weapons Related
White	Nougat	05/25/1962	NTS	Shaft	Weapons Related
Tanana	Nougat	05/25/1962	Christmas Island Area	Airdrop	Weapons Related
Truckee	Nougat	06/09/1962	Christmas Island Area	Airdrop	Weapons Related
Harlem	Nougat	06/12/1962	Christmas Island Area	Airdrop	Weapons Related
Des Moines	Nougat	06/13/1962	NTS	Tunnel	Weapons Related
Petit	Nougat	06/19/1962	Christmas Island Area	Airdrop	Weapons Related
Bighorn	Nougat	06/27/1962	Christmas Island Area	Airdrop	Weapons Related
Marshmallow	Nougat	06/28/1962	NTS	Tunnel	Weapons Related
Bluestone	Nougat	06/30/1962	Christmas Island Area	Airdrop	Weapons Related
Sacramento	Nougat	06/30/1962	NTS	Shaft	Weapons Related
Sedan	Storax	07/06/1962	NTS	Crater	Plowshare
Pamlico	Storax	07/11/1962	Christmas Island Area	Airdrop	Weapons Related
Johnnie Boy	Storax	07/11/1962	NTS	Crater	Weapons Effects
Merrimac	Storax	07/13/1962	NTS	Shaft	Weapons Related
Wichita	Storax	07/27/1962	NTS	Shaft	Weapons Related
York	Storax	08/24/1962	NTS	Shaft	Weapons Related
Raritan	Storax	09/06/1962	NTS	Shaft	Weapons Related
Allegheny	Storax	09/29/1962	NTS	Shaft	Weapons Related
Androscoggin	Storax	10/02/1962	Johnston Island Area	Airdrop	Weapons Related
Mississippi	Storax	10/05/1962	NTS	Shaft	Weapons Related
Bumping	Storax	10/06/1962	Johnston Island Area	Airdrop	Weapons Related
Roanoke	Storax	10/12/1962	NTS	Shaft	Weapons Related
Tioga	Storax	10/18/1962	NTS	Shaft	Weapons Related
Santee	Storax	10/27/1962	NTS	Shaft	Weapons Related
Calamity	Storax	10/27/1962	Johnston Island Area	Airdrop	Weapons Related
Housatonic	Storax	10/30/1962	Johnston Island Area	Airdrop	Weapons Related
St. Lawrence	Storax	11/09/1962	NTS	Shaft	Weapons Related
Anacostia	Storax	11/27/1962	NTS	Shaft	Plowshare
Taunton	Storax	12/04/1962	NTS	Shaft	Weapons Related
Madison	Storax	12/12/1962	NTS	Tunnel	Weapons Related

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Table A6-1: Lawrence Livermore National Laboratory-Sponsored Atmospheric Weapons Tests, Underwater Weapons Tests, and Special Projects

Source: DOE 2000

Test Name	Operation	Date	Location	Type	Purpose
Manatee	Storax	12/14/1962	NTS	Shaft	Weapons Related
Casselman	Storax	02/08/1963	NTS	Shaft	Weapons Related
Hatchie	Storax	02/08/1963	NTS	Shaft	Weapons Related
Kaweah	Storax	02/21/1963	NTS	Shaft	Plowshare
Carmel	Storax	02/21/1963	NTS	Shaft	Weapons Related
Toyah	Storax	03/15/1963	NTS	Shaft	Weapons Related
Cumberland	Storax	04/11/1963	NTS	Shaft	Weapons Related
Kootanai	Storax	04/24/1963	NTS	Shaft	Weapons Related
Paisano	Storax	04/24/1963	NTS	Shaft	Weapons Related
Pleasant	Storax	05/29/1963	NTS	Shaft	Weapons Related
Yuba	Storax	06/05/1963	NTS	Tunnel	Weapons Related
Apshapa	Storax	06/06/1963	NTS	Shaft	Weapons Related
Kennebec	Storax	06/25/1963	NTS	Shaft	Weapons Related
Satsop	Niblick	08/12/1963	NTS	Shaft	Weapons Related
Kohocton	Niblick	08/23/1963	NTS	Shaft	Weapons Related
Natches	Niblick	08/23/1963	NTS	Shaft	Weapons Related
Ahtanum	Niblick	09/13/1963	NTS	Shaft	Weapons Related
Narraguagus	Niblick	09/27/1963	NTS	Shaft	Weapons Related
Tomillo	Niblick	10/11/1963	NTS	Shaft	Plowshare
Clearwater	Niblick	10/16/1963	NTS	Shaft	Weapons Related
Mullet	Niblick	10/17/1963	NTS	Shaft	Safety Experiment
Mustang	Niblick	11/15/1963	NTS	Shaft	Weapons Related
Greys	Niblick	11/22/1963	NTS	Shaft	Weapons Related
Eagle	Niblick	12/12/1963	NTS	Shaft	Weapons Related
Fore	Niblick	01/16/1964	NTS	Shaft	Weapons Related
Oconto	Niblick	01/23/1964	NTS	Shaft	Weapons Related
Club	Niblick	01/30/1964	NTS	Shaft	Weapons Related
Bunker	Niblick	02/13/1964	NTS	Shaft	Weapons Related
Kickitat	Niblick	02/20/1964	NTS	Shaft	Plowshare
Handicap	Niblick	03/12/1964	NTS	Shaft	Weapons Related
Hook	Niblick	04/14/1964	NTS	Shaft	Weapons Related
Bogey	Niblick	04/17/1964	NTS	Shaft	Weapons Related
Turf	Niblick	04/24/1964	NTS	Shaft	Weapons Related
Driver	Niblick	05/07/1964	NTS	Shaft	Weapons Related
Backswing	Niblick	05/14/1964	NTS	Shaft	Weapons Related

Table A6-1: Lawrence Livermore National Laboratory-Sponsored Atmospheric Weapons Tests, Underwater Weapons Tests, and Special Projects

Source: DOE 2000

Test Name	Operation	Date	Location	Type	Purpose
Ace	Niblick	06/11/1964	NTS	Shaft	Plowshare
Duffer	Niblick	06/18/1964	NTS	Shaft	Weapons Related
Fade	Niblick	06/25/1964	NTS	Shaft	Weapons Related
Dub	Niblick	06/30/1964	NTS	Shaft	Plowshare
Bye	Whetstone	07/16/1964	NTS	Shaft	Weapons Related
Links	Whetstone	07/23/1964	NTS	Shaft	Weapons Related
Alva	Whetstone	08/19/1964	NTS	Shaft	Weapons Related
Player	Whetstone	08/27/1964	NTS	Shaft	Safety Experiment
Spoon	Whetstone	09/11/1964	NTS	Shaft	Weapons Related
Par	Whetstone	10/09/1964	NTS	Shaft	Plowshare
Salmon	Whetstone	10/22/1964	Hattiesburg, Mississippi	Shaft	Vela Uniform
Garden	Whetstone	10/23/1964	NTS	Shaft	Weapons Related
Forest	Whetstone	10/31/1964	NTS	Shaft	Weapons Related
Handcar	Whetstone	11/05/1964	NTS	Shaft	Plowshare
Crepe	Whetstone	12/05/1964	NTS	Shaft	Weapons Related
Drill (Source-Lower)	Whetstone	12/05/1964	NTS	Shaft	Weapons Related
Drill (Target-Upper)	Whetstone	12/05/1964	NTS	Shaft	Weapons Related
Mudpack	Whetstone	12/16/1964	NTS	Shaft	Weapons Effects
Sulky	Whetstone	12/18/1964	NTS	Shaft	Plowshare
Wool	Whetstone	01/14/1965	NTS	Shaft	Weapons Related
Cashmere	Whetstone	02/04/1965	NTS	Shaft	Weapons Related
Alpaca	Whetstone	02/12/1965	NTS	Shaft	Weapons Related
Wishbone	Whetstone	02/18/1965	NTS	Shaft	Weapons Effects
Seersucker	Whetstone	02/19/1965	NTS	Shaft	Weapons Related
Suede	Whetstone	03/20/1965	NTS	Shaft	Weapons Related
Cup	Whetstone	03/20/1965	NTS	Shaft	Weapons Related
Palanquin	Whetstone	04/14/1965	NTS	Crater	Plowshare
Gum Drop	Whetstone	04/21/1965	NTS	Tunnel	Weapons Effects
Chenille	Whetstone	04/22/1965	NTS	Shaft	Weapons Related
Tee	Whetstone	05/07/1965	NTS	Shaft	Weapons Effects
Cambric	Whetstone	05/14/1965	NTS	Shaft	Weapons Related
Tweed	Whetstone	05/21/1965	NTS	Shaft	Weapons Related
Organdy	Whetstone	06/11/1965	NTS	Shaft	Weapons Related
Diluted Waters	Whetstone	06/16/1965	NTS	Shaft	Weapons Effects
Tiny Tot	Whetstone	06/17/1965	NTS	Tunnel	Weapons Effects

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Table A6-1: Lawrence Livermore National Laboratory-Sponsored Atmospheric Weapons Tests, Underwater Weapons Tests, and Special Projects

Source: DOE 2000

Test Name	Operation	Date	Location	Type	Purpose
Izzer	Flintlock	07/16/1965	NTS	Shaft	Weapons Related
Pongee	Flintlock	07/22/1965	NTS	Shaft	Weapons Related
Ticking	Flintlock	08/21/1965	NTS	Shaft	Weapons Related
Centaur	Flintlock	08/27/1965	NTS	Shaft	Weapons Related
Elkhart	Flintlock	09/17/1965	NTS	Shaft	Weapons Related
Kermet	Flintlock	11/23/1965	NTS	Shaft	Weapons Related
Corduroy	Flintlock	12/03/1965	NTS	Shaft	Weapons Related
Emerson	Flintlock	12/16/1965	NTS	Shaft	Weapons Related
Maxwell	Flintlock	01/13/1966	NTS	Shaft	Weapons Related
Reo	Flintlock	01/22/1966	NTS	Shaft	Weapons Related
Plaid II	Flintlock	02/03/1966	NTS	Shaft	Weapons Related
Rex	Flintlock	02/24/1966	NTS	Shaft	Weapons Related
Finfoot	Flintlock	03/07/1966	NTS	Shaft	Weapons Related
Clymer	Flintlock	03/12/1966	NTS	Shaft	Weapons Related
Templar	Flintlock	03/24/1966	NTS	Shaft	Weapons Related
Stutz	Flintlock	04/06/1966	NTS	Shaft	Weapons Related
Duryea	Flintlock	04/14/1966	NTS	Shaft	Weapons Related
Fenton	Flintlock	04/23/1966	NTS	Shaft	Weapons Related
Traveler	Flintlock	05/04/1966	NTS	Shaft	Weapons Related
Tapestry	Flintlock	05/12/1966	NTS	Shaft	Weapons Related
Dumont	Flintlock	05/19/1966	NTS	Shaft	Weapons Related
Double Play	Flintlock	06/15/1966	NTS	Tunnel	Weapons Effects
Kankakee	Flintlock	06/15/1966	NTS	Shaft	Weapons Related
Vulcan	Flintlock	06/25/1966	NTS	Shaft	Plowshare
Saxon	Latchkey	07/28/1966	NTS	Shaft	Plowshare
Rovena	Latchkey	08/10/1966	NTS	Shaft	Weapons Related
Newark	Latchkey	09/29/1966	NTS	Shaft	Weapons Related
Simms	Latchkey	11/05/1966	NTS	Shaft	Plowshare
Ajax	Latchkey	11/11/1966	NTS	Shaft	Weapons Related
Vigil	Latchkey	11/22/1966	NTS	Shaft	Safety Experiment
Sterling	Latchkey	12/03/1966	Hattiesburg, Mississippi	Shaft	Vela Uniform
New Point	Latchkey	12/13/1966	NTS	Shaft	Weapons Effects
Greeley	Latchkey	12/20/1966	NTS	Shaft	Weapons Related
Rivet I	Latchkey	01/18/1967	NTS	Shaft	Weapons Related
Nash	Latchkey	01/19/1967	NTS	Shaft	Weapons Related

Table A6-1: Lawrence Livermore National Laboratory-Sponsored Atmospheric Weapons Tests, Underwater Weapons Tests, and Special Projects

Source: DOE 2000

Test Name	Operation	Date	Location	Type	Purpose
Rivet II	Latchkey	01/26/1967	NTS	Shaft	Weapons Related
Ward	Latchkey	02/08/1967	NTS	Shaft	Weapons Related
Agile	Latchkey	02/23/1967	NTS	Shaft	Weapons Related
Rivet III	Latchkey	03/02/1967	NTS	Shaft	Weapons Related
Oakland	Latchkey	04/04/1967	NTS	Shaft	Weapons Related
Heilman	Latchkey	04/06/1967	NTS	Shaft	Weapons Related
Effendi	Latchkey	04/27/1967	NTS	Shaft	Weapons Related
Commodore	Latchkey	05/20/1967	NTS	Shaft	Weapons Related
Knickerbocker	Latchkey	05/26/1967	NTS	Shaft	Weapons Related
Switch	Latchkey	06/22/1967	NTS	Shaft	Plowshare
Midi Mist	Latchkey	06/26/1967	NTS	Tunnel	Weapons Effects
Vito	Crosstie	07/14/1967	NTS	Shaft	Safety Experiment
Stanley	Crosstie	07/27/1967	NTS	Shaft	Weapons Related
Washer	Crosstie	08/10/1967	NTS	Shaft	Weapons Related
Lexington	Crosstie	08/24/1967	NTS	Shaft	Weapons Related
Yard	Crosstie	09/07/1967	NTS	Shaft	Weapons Related
Marvel	Crosstie	09/21/1967	NTS	Shaft	Plowshare
Lanpher	Crosstie	10/18/1967	NTS	Shaft	Weapons Related
Worth	Crosstie	10/25/1967	NTS	Shaft	Weapons Related
Polka	Crosstie	12/16/1967	NTS	Shaft	Weapons Related
Gasbuggy	Crosstie	12/10/1967	Farmington, New Mexico	Shaft	Plowshare
Hupmobile	Crosstie	01/18/1968	NTS	Shaft	Weapons Effects
Staccato	Crosstie	01/19/1968	NTS	Shaft	Weapons Related
Faultless	Crosstie	01/19/1968	Central Nevada	Shaft	Weapons Related
Cabriolet	Crosstie	01/26/1968	NTS	Crater	Plowshare
Knox	Crosstie	02/21/1968	NTS	Shaft	Weapons Related
Buggy A	Crosstie	03/12/1968	NTS	Crater	Plowshare
Buggy B	Crosstie	03/12/1968	NTS	Crater	Plowshare
Buggy C	Crosstie	03/12/1968	NTS	Crater	Plowshare
Buggy D	Crosstie	03/12/1968	NTS	Crater	Plowshare
Buggy D	Crosstie	03/12/1968	NTS	Crater	Plowshare
Milk Shake	Crosstie	03/25/1968	NTS	Shaft	Weapons Effects
Noor	Crosstie	04/10/1968	NTS	Shaft	Weapons Related
Throw	Crosstie	04/10/1968	NTS	Shaft	Weapons Related
Shuffle	Crosstie	04/18/1968	NTS	Shaft	Weapons Related

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Table A6-1: Lawrence Livermore National Laboratory-Sponsored Atmospheric Weapons Tests, Underwater Weapons Tests, and Special Projects

Source: DOE 2000

Test Name	Operation	Date	Location	Type	Purpose
Scroll	Crosstie	04/23/1968	NTS	Shaft	Vela Uniform
Boxcar	Crosstie	04/26/1968	NTS	Shaft	Weapons Related
Crock	Crosstie	05/08/1968	NTS	Shaft	Weapons Related
Clarksmobile	Crosstie	05/17/1968	NTS	Shaft	Weapons Related
Tub A	Crosstie	06/06/1968	NTS	Shaft	Weapons Related
Tub B	Crosstie	06/06/1968	NTS	Shaft	Weapons Related
Tub C	Crosstie	06/06/1968	NTS	Shaft	Weapons Related
Tub D	Crosstie	06/06/1968	NTS	Shaft	Weapons Related
Tub F	Crosstie	06/06/1968	NTS	Shaft	Weapons Related
Chateaugay	Crosstie	06/28/1968	NTS	Shaft	Weapons Related
Tanya	Bowline	07/30/1968	NTS	Shaft	Weapons Related
Imp	Bowline	08/09/1968	NTS	Shaft	Weapons Related
Rack	Bowline	08/15/1968	NTS	Shaft	Weapons Related
Diana Moon	Bowline	08/27/1968	NTS	Shaft	Weapons Effects
Noggin	Bowline	09/06/1968	NTS	Shaft	Weapons Related
Stoddard	Bowline	09/17/1968	NTS	Shaft	Plowshare
Hudson Seal	Bowline	09/24/1968	NTS	Tunnel	Weapons Effects
Vat	Bowline	10/10/1968	NTS	Shaft	Weapons Related
Hula	Bowline	10/29/1968	NTS	Shaft	Weapons Related
Crew	Bowline	11/04/1968	NTS	Shaft	Weapons Related
Crew 2nd	Bowline	11/04/1968	NTS	Shaft	Weapons Related
Crew 3rd	Bowline	11/04/1968	NTS	Shaft	Weapons Related
Tinderbox	Bowline	11/22/1968	NTS	Shaft	Weapons Related
Schooner	Bowline	12/08/1968	NTS	Crater	Plowshare
Tyg A	Bowline	12/12/1968	NTS	Shaft	Weapons Related
Tyg B	Bowline	12/12/1968	NTS	Shaft	Weapons Related
Tyg C	Bowline	12/12/1968	NTS	Shaft	Weapons Related
Tyg D	Bowline	12/12/1968	NTS	Shaft	Weapons Related
Tyg E	Bowline	12/12/1968	NTS	Shaft	Weapons Related
Tyg F	Bowline	12/12/1968	NTS	Shaft	Weapons Related
Benham	Bowline	12/19/1968	NTS	Shaft	Weapons Related
Packard	Bowline	01/15/1969	NTS	Shaft	Weapons Effects
Wineskin	Bowline	01/15/1969	NTS	Shaft	Weapons Related
Biggin	Bowline	01/30/1969	NTS	Shaft	Weapons Related
Cypress	Bowline	02/12/1969	NTS	Tunnel	Weapons Effects

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Table A6-1: Lawrence Livermore National Laboratory-Sponsored Atmospheric Weapons Tests, Underwater Weapons Tests, and Special Projects

Source: DOE 2000

Test Name	Operation	Date	Location	Type	Purpose
Valise	Bowline	03/18/1969	NTS	Shaft	Safety Experiment
Chatty	Bowline	03/18/1969	NTS	Shaft	Weapons Related
Coffer	Bowline	03/21/1969	NTS	Shaft	Weapons Related
Gourd-Amber	Bowline	04/24/1969	NTS	Shaft	Weapons Related
Gourd-Brown	Bowline	04/24/1969	NTS	Shaft	Weapons Related
Purse	Bowline	05/07/1969	NTS	Shaft	Weapons Related
Bowl 1	Bowline	06/26/1969	NTS	Shaft	Weapons Related
Bowl 2	Bowline	06/26/1969	NTS	Shaft	Weapons Related
Ildrim	Mandrel	07/16/1969	NTS	Shaft	Weapons Related
Hutch	Mandrel	07/16/1969	NTS	Shaft	Weapons Related
Spider A	Mandrel	08/14/1969	NTS	Shaft	Weapons Related
Spider B	Mandrel	08/14/1969	NTS	Shaft	Weapons Related
Minute Steak	Mandrel	09/12/1969	NTS	Shaft	Weapons Effects
Jorum	Mandrel	09/16/1969	NTS	Shaft	Weapons Related
Kyack A	Mandrel	09/20/1969	NTS	Shaft	Weapons Related
Kyack B	Mandrel	09/20/1969	NTS	Shaft	Weapons Related
Pipkin	Mandrel	10/08/1969	NTS	Shaft	Weapons Related
Cruet	Mandrel	10/29/1969	NTS	Shaft	Weapons Related
Pod A	Mandrel	10/29/1969	NTS	Shaft	Weapons Related
Pod B	Mandrel	10/29/1969	NTS	Shaft	Weapons Related
Pod C	Mandrel	10/29/1969	NTS	Shaft	Weapons Related
Pod D	Mandrel	10/29/1969	NTS	Shaft	Weapons Related
Calabash	Mandrel	10/29/1969	NTS	Shaft	Weapons Related
Scuttle	Mandrel	11/13/1969	NTS	Shaft	Weapons Related
Tun A	Mandrel	12/10/1969	NTS	Shaft	Weapons Related
Tun B	Mandrel	12/10/1969	NTS	Shaft	Weapons Related
Tun C	Mandrel	12/10/1969	NTS	Shaft	Weapons Related
Tun D	Mandrel	12/10/1969	NTS	Shaft	Weapons Related
Terrine White	Mandrel	12/18/1969	NTS	Shaft	Weapons Related
Terrine Yellow	Mandrel	12/18/1969	NTS	Shaft	Weapons Related
Fob Green	Mandrel	01/23/1970	NTS	Shaft	Weapons Related
Fob Red	Mandrel	01/23/1970	NTS	Shaft	Weapons Related
Fob Blue	Mandrel	01/23/1970	NTS	Shaft	Weapons Related
Yannigan Red	Mandrel	02/26/1970	NTS	Shaft	Weapons Related
Yannigan Blue	Mandrel	02/26/1970	NTS	Shaft	Weapons Related

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Table A6-1: Lawrence Livermore National Laboratory-Sponsored Atmospheric Weapons Tests, Underwater Weapons Tests, and Special Projects

Source: DOE 2000

Test Name	Operation	Date	Location	Type	Purpose
Yannigan White	Mandrel	02/26/1970	NTS	Shaft	Weapons Related
Cyathus	Mandrel	03/06/1970	NTS	Shaft	Weapons Related
Arabis Red	Mandrel	03/06/1970	NTS	Shaft	Weapons Related
Arabis Green	Mandrel	03/06/1970	NTS	Shaft	Weapons Related
Arabis Blue	Mandrel	03/06/1970	NTS	Shaft	Safety Experiment
Handley	Mandrel	03/26/1970	NTS	Shaft	Weapons Related
Can Green	Mandrel	04/21/1970	NTS	Shaft	Weapons Related
Can Red	Mandrel	04/21/1970	NTS	Shaft	Weapons Related
Hod A (Green)	Mandrel	05/01/1970	NTS	Shaft	Weapons Related
Hod B (Red)	Mandrel	05/01/1970	NTS	Shaft	Weapons Related
Hod C (Blue)	Mandrel	05/01/1970	NTS	Shaft	Safety Experiment
Mint Leaf	Mandrel	05/05/1970	NTS	Tunnel	Weapons Effects
Cornice Yellow	Mandrel	05/15/1970	NTS	Shaft	Weapons Related
Cornice Green	Mandrel	05/15/1970	NTS	Shaft	Weapons Related
Hudson Moon	Mandrel	05/26/1970	NTS	Tunnel	Weapons Effects
Flask Green	Mandrel	05/26/1970	NTS	Shaft	Plowshare
Flask Yellow	Mandrel	05/26/1970	NTS	Shaft	Plowshare
Flask Red	Mandrel	05/26/1970	NTS	Shaft	Plowshare
Piton C	Mandrel	05/28/1970	NTS	Shaft	Weapons Related
Piton A	Mandrel	05/28/1970	NTS	Shaft	Weapons Related
Piton B	Mandrel	05/28/1970	NTS	Shaft	Weapons Related
Arnica Yellow	Mandrel	06/26/1970	NTS	Shaft	Weapons Related
Arnica Violet	Mandrel	06/26/1970	NTS	Shaft	Weapons Related
Scree Acajou	Emery	10/13/1970	NTS	Shaft	Weapons Related
Scree Alhambra	Emery	10/13/1970	NTS	Shaft	Weapons Related
Scree Chamois	Emery	10/13/1970	NTS	Shaft	Safety Experiment
Avens Andorre	Emery	12/16/1970	NTS	Shaft	Weapons Related
Avens Alkermes	Emery	12/16/1970	NTS	Shaft	Weapons Related
Avens Asamite	Emery	12/16/1970	NTS	Shaft	Weapons Related
Avens Cream	Emery	12/16/1970	NTS	Shaft	Weapons Related
Carpetbag	Emery	12/17/1970	NTS	Shaft	Weapons Related
Baneberry	Emery	12/18/1970	NTS	Shaft	Weapons Related
Hareball	Emery	06/24/1970	NTS	Shaft	Weapons Related
Camphor	Emery	06/29/1970	NTS	Tunnel	Weapons Effects
Miniata	Grommet	07/08/1971	NTS	Shaft	Plowshare

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Table A6-1: Lawrence Livermore National Laboratory-Sponsored Atmospheric Weapons Tests, Underwater Weapons Tests, and Special Projects

Source: DOE 2000

Test Name	Operation	Date	Location	Type	Purpose
Bracken	Grommet	07/09/1971	NTS	Shaft	Weapons Related
Nama Amarylis	Grommet	08/05/1971	NTS	Shaft	Weapons Related
Nama Mephisto	Grommet	08/05/1971	NTS	Shaft	Weapons Related
Baltic	Grommet	08/06/1971	NTS	Shaft	Weapons Related
Chantilly	Grommet	09/29/1971	NTS	Shaft	Weapons Related
Cathay	Grommet	10/08/1971	NTS	Shaft	Weapons Related
Lagoon	Grommet	10/14/1971	NTS	Shaft	Weapons Related
Cannikin	Grommet	11/06/1971	Amchitka, Alaska	Shaft	Weapons Related
Diagonal Line	Grommet	11/24/1971	NTS	Shaft	Weapons Effects
Parnassia	Grommet	11/30/1971	NTS	Shaft	Weapons Related
Chaenactis	Grommet	12/14/1971	NTS	Shaft	Weapons Related
Dianthus	Grommet	02/17/1972	NTS	Shaft	Weapons Related
Sappho	Grommet	03/23/1972	NTS	Shaft	Weapons Related
Longchamps	Grommet	04/19/1972	NTS	Shaft	Weapons Related
Kara	Grommet	05/11/1972	NTS	Shaft	Weapons Related
Zinnia	Grommet	05/17/1972	NTS	Shaft	Weapons Related
Merida	Grommet	06/07/1972	NTS	Shaft	Weapons Related
Haplopappus	Grommet	06/28/1972	NTS	Shaft	Weapons Related
Diamond Sculls	Toggle	07/20/1972	NTS	Tunnel	Weapons Effects
Delphinium	Toggle	09/26/1972	NTS	Shaft	Weapons Related
Akbar	Toggle	11/09/1972	NTS	Shaft	Weapons Related
Arsenate	Toggle	11/19/1972	NTS	Shaft	Weapons Related
Canna Umbrinus	Toggle	11/17/1972	NTS	Shaft	Weapons Related
Canna Limoges	Toggle	11/17/1972	NTS	Shaft	Safety Experiment
Solanum	Toggle	12/14/1972	NTS	Shaft	Weapons Related
Flax Source	Toggle	12/21/1972	NTS	Shaft	Weapons Related
Flax Test	Toggle	12/21/1972	NTS	Shaft	Weapons Effects
Flax Backup	Toggle	12/21/1972	NTS	Shaft	Weapons Effects
Alumroot	Toggle	02/14/1973	NTS	Shaft	Weapons Related
Gazook	Toggle	03/23/1973	NTS	Shaft	Weapons Related
Natoma	Toggle	04/05/1973	NTS	Shaft	Weapons Related
Starwort	Toggle	04/26/1973	NTS	Shaft	Weapons Related
Rio Blanco 1	Toggle	05/17/1973	Rifle, Colorado	Shaft	Plowshare
Rio Blanco 2	Toggle	05/17/1973	Rifle, Colorado	Shaft	Plowshare
Rio Blanco 3	Toggle	05/17/1973	Rifle, Colorado	Shaft	Plowshare

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Table A6-1: Lawrence Livermore National Laboratory-Sponsored Atmospheric Weapons Tests, Underwater Weapons Tests, and Special Projects

Source: DOE 2000

Test Name	Operation	Date	Location	Type	Purpose
Kashan	Toggle	05/24/1973	NTS	Shaft	Weapons Related
Dido Queen	Toggle	06/05/1973	NTS	Tunnel	Weapons Effects
Portulaca	Toggle	06/28/1973	NTS	Shaft	Weapons Related
Silene	Toggle	06/28/1973	NTS	Shaft	Weapons Related
Polygonum	Arbor	10/02/1973	NTS	Shaft	Weapons Related
Waller	Arbor	10/02/1973	NTS	Shaft	Weapons Related
Seafoam	Arbor	12/13/1973	NTS	Shaft	Weapons Related
Pinedrops Sloat	Arbor	01/10/1974	NTS	Shaft	Weapons Related
Pinedrops Tawny	Arbor	01/10/1974	NTS	Shaft	Weapons Related
Pinedrops Bayou	Arbor	01/10/1974	NTS	Shaft	Weapons Related
Hulsea	Arbor	03/14/1974	NTS	Shaft	Weapons Related
Potrero	Arbor	04/23/1974	NTS	Shaft	Weapons Related
Grove	Arbor	05/22/1974	NTS	Shaft	Weapons Related
Fallon	Arbor	05/23/1974	NTS	Shaft	Joint US-UK
Crestlake Tansan	Bedrock	07/18/1974	NTS	Shaft	Weapons Related
Crestlake Briar	Bedrock	07/18/1974	NTS	Shaft	Weapons Related
Portmanteau	Bedrock	08/30/1974	NTS	Shaft	Weapons Related
Stanyan	Bedrock	09/26/1974	NTS	Shaft	Weapons Related
Trumbull	Bedrock	09/26/1974	NTS	Shaft	Weapons Related
Hybla Fair	Bedrock	10/28/1974	NTS	Tunnel	Weapons Effects
Temescal	Bedrock	11/02/1974	NTS	Shaft	Weapons Related
Portola	Bedrock	02/06/1975	NTS	Shaft	Weapons Related
Portola Larkin	Bedrock	02/06/1975	NTS	Shaft	Weapons Related
Teleme	Bedrock	02/06/1975	NTS	Shaft	Weapons Related
Cabrillo	Bedrock	03/07/1975	NTS	Shaft	Weapons Related
Dining Car	Bedrock	04/05/1975	NTS	Tunnel	Weapons Effects
Edam	Bedrock	04/24/1975	NTS	Shaft	Weapons Related
Tybo	Bedrock	05/14/1975	NTS	Shaft	Weapons Related
Stilton	Bedrock	06/03/1975	NTS	Shaft	Weapons Related
Alviso	Bedrock	06/11/1975	NTS	Shaft	Safety Experiment
Camembert	Bedrock	06/26/1975	NTS	Shaft	Weapons Related
Husky Pup	Anvil	10/24/1975	NTS	Tunnel	Weapons Effects
Kasseri	Anvil	10/28/1975	NTS	Shaft	Weapons Related
Leyden	Anvil	11/26/1975	NTS	Shaft	Weapons Related
Chiberta	Anvil	12/20/1975	NTS	Shaft	Weapons Related

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Table A6-1: Lawrence Livermore National Laboratory-Sponsored Atmospheric Weapons Tests, Underwater Weapons Tests, and Special Projects

Source: DOE 2000

Test Name	Operation	Date	Location	Type	Purpose
Muenster	Anvil	01/03/1976	NTS	Shaft	Weapons Related
Esrom	Anvil	02/04/1976	NTS	Shaft	Weapons Related
Fontina	Anvil	02/12/1976	NTS	Shaft	Weapons Related
Cheshire	Anvil	02/14/1976	NTS	Shaft	Weapons Related
Colby	Anvil	03/14/1976	NTS	Shaft	Weapons Related
Mighty Epic	Anvil	05/12/1976	NTS	Tunnel	Weapons Effects
Rivoli	Anvil	05/20/1976	NTS	Shaft	Weapons Related
Banon	Anvil	08/26/1976	NTS	Shaft	Joint US-UK
Gouda	Fulcrum	10/16/1976	NTS	Shaft	Weapons Related
Chevre	Fulcrum	11/23/1976	NTS	Shaft	Weapons Related
Asiago	Fulcrum	12/21/1976	NTS	Shaft	Weapons Related
Sutter	Fulcrum	12/21/1976	NTS	Shaft	Weapons Related
Dofino	Fulcrum	03/08/1977	NTS	Shaft	Weapons Related
Dofino Lawton	Fulcrum	03/08/1977	NTS	Shaft	Weapons Related
Marsilly	Fulcrum	04/05/1977	NTS	Shaft	Weapons Related
Carnelian	Fulcrum	07/28/1977	NTS	Shaft	Weapons Related
Flotost	Fulcrum	08/16/1977	NTS	Shaft	Weapons Related
Gruyere	Fulcrum	08/16/1977	NTS	Shaft	Weapons Related
Gruyere Gradino	Fulcrum	08/16/1977	NTS	Shaft	Weapons Related
Coulommiers	Fulcrum	09/27/1977	NTS	Shaft	Weapons Related
Farallones	Cresset	12/14/1977	NTS	Shaft	Weapons Related
Campos	Cresset	02/13/1978	NTS	Shaft	Weapons Related
Reblochon	Cresset	02/23/1978	NTS	Shaft	Weapons Related
Karab	Cresset	03/16/1978	NTS	Shaft	Weapons Related
Fondutta	Cresset	04/11/1978	NTS	Shaft	Joint US-UK
Asco	Cresset	04/25/1978	NTS	Shaft	Safety Experiment
Satz	Cresset	07/07/1978	NTS	Shaft	Weapons Related
Panir	Cresset	08/31/1978	NTS	Shaft	Weapons Related
Diablo Hawk	Cresset	09/13/1978	NTS	Tunnel	Weapons Effects
Cremino	Cresset	09/27/1978	NTS	Shaft	Weapons Related
Cremino Caerphilly	Cresset	09/27/1978	NTS	Shaft	Weapons Related
Emmenthal	Quicksilver	11/02/1978	NTS	Shaft	Weapons Related
Quargel	Quicksilver	11/18/1978	NTS	Shaft	Joint US-UK
Farm	Quicksilver	12/16/1978	NTS	Shaft	Weapons Related
Kloster	Quicksilver	02/15/1979	NTS	Shaft	Weapons Related

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Table A6-1: Lawrence Livermore National Laboratory-Sponsored Atmospheric Weapons Tests, Underwater Weapons Tests, and Special Projects

Source: DOE 2000

Test Name	Operation	Date	Location	Type	Purpose
Pepato	Quicksilver	06/11/1979	NTS	Shaft	Weapons Related
Fajy	Quicksilver	06/28/1979	NTS	Shaft	Weapons Related
Burzet	Quicksilver	08/03/1979	NTS	Shaft	Weapons Related
Nessel	Quicksilver	08/29/1979	NTS	Shaft	Joint US-UK
Pera	Quicksilver	09/08/1979	NTS	Shaft	Weapons Related
Azul	Tinderbox	12/14/1979	NTS	Shaft	Weapons Related
Tarko	Tinderbox	02/28/1980	NTS	Shaft	Weapons Related
Norbo	Tinderbox	03/08/1980	NTS	Shaft	Weapons Related
Liptauer	Tinderbox	04/03/01980	NTS	Shaft	Weapons Related
Colwick	Tinderbox	04/26/1980	NTS	Shaft	Joint US-UK
Kash	Tinderbox	06/12/1980	NTS	Shaft	Weapons Related
Tafi	Tinderbox	07/25/1980	NTS	Shaft	Weapons Related
Riola	Tinderbox	09/25/1980	NTS	Shaft	Weapons Related
Dauphin	Guardian	11/14/1980	NTS	Shaft	Weapons Related
Serpa	Guardian	12/17/1980	NTS	Shaft	Joint US-UK
Seco	Guardian	02/25/1981	NTS	Shaft	Weapons Related
Vide	Guardian	04/30/1981	NTS	Shaft	Weapons Related
Harzer	Guardian	06/06/1981	NTS	Shaft	Weapons Related
Niza	Guardian	07/10/1981	NTS	Shaft	Weapons Related
Havarti	Guardian	08/05/1981	NTS	Shaft	Weapons Related
Islay	Guardian	08/27/1981	NTS	Shaft	Weapons Related
Akavi	Praetorian	12/03/1981	NTS	Shaft	Weapons Related
Caboc	Praetorian	12/16/1981	NTS	Shaft	Weapons Related
Molbo	Praetorian	02/12/1982	NTS	Shaft	Weapons Related
Gibne	Praetorian	04/25/1982	NTS	Shaft	Joint US-UK
Kryddost	Praetorian	05/16/1982	NTS	Shaft	Weapons Related
Kesti	Praetorian	06/16/1982	NTS	Shaft	Weapons Related
Monterey	Praetorian	07/29/1982	NTS	Shaft	Weapons Related
Queso	Praetorian	08/11/1982	NTS	Shaft	Weapons Related
Huron Landing	Praetorian	09/23/1982	NTS	Tunnel	Weapons Effects
Diamond Ace	Praetorian	09/23/1982	NTS	Tunnel	Weapons Effects
Frisco	Praetorian	09/23/1982	NTS	Shaft	Weapons Related
Manteca	Phalanx	12/10/1982	NTS	Shaft	Weapons Related
Cheedam	Phalanx	02/17/1983	NTS	Shaft	Weapons Related
Cabra	Phalanx	03/26/1983	NTS	Shaft	Weapons Related

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Table A6-1: Lawrence Livermore National Laboratory-Sponsored Atmospheric Weapons Tests, Underwater Weapons Tests, and Special Projects

Source: DOE 2000

Test Name	Operation	Date	Location	Type	Purpose
Armada	Phalanx	04/22/1983	NTS	Shaft	Joint US-UK
Crowdie	Phalanx	05/05/1983	NTS	Shaft	Weapons Related
Danablu	Phalanx	06/09/1983	NTS	Shaft	Weapons Related
Laban	Phalanx	08/03/1983	NTS	Shaft	Weapons Related
Jarlsberg	Phalanx	08/27/1983	NTS	Shaft	Weapons Related
Tomme/Midnight Zephyr	Phalanx	09/21/1983	NTS	Tunnel	Weapons Effects
Branco	Phalanx	09/21/1983	NTS	Shaft	Weapons Related
Branco Herkimer	Phalanx	09/21/1983	NTS	Shaft	Weapons Related
Romano	Fusileer	12/16/1983	NTS	Shaft	Weapons Related
Gorbea	Fusileer	01/31/1984	NTS	Shaft	Weapons Related
Agrini	Fusileer	03/31/1984	NTS	Shaft	Weapons Related
Orkney	Fusileer	05/02/1984	NTS	Shaft	Weapons Related
Bellow	Fusileer	05/16/1984	NTS	Shaft	Weapons Related
Normanna	Fusileer	07/12/1984	NTS	Shaft	Weapons Related
Kappeli	Fusileer	07/25/1984	NTS	Shaft	Weapons Related
Wexford	Fusileer	08/30/1984	NTS	Shaft	Weapons Related
Breton	Fusileer	09/13/1984	NTS	Shaft	Weapons Related
Egmont	Grenadier	12/09/1984	NTS	Shaft	Joint US-UK
Tierra	Grenadier	12/15/1984	NTS	Shaft	Weapons Related
Cottage	Grenadier	03/23/1985	NTS	Shaft	Weapons Related
Towanda	Grenadier	05/02/1985	NTS	Shaft	Weapons Related
Salut	Grenadier	06/12/1985	NTS	Shaft	Weapons Related
Ville	Grenadier	06/12/1985	NTS	Shaft	Weapons Related
Maribo	Grenadier	06/26/1985	NTS	Shaft	Weapons Related
Serena	Grenadier	07/25/1985	NTS	Shaft	Weapons Related
Cebrero	Grenadier	08/14/1985	NTS	Shaft	Weapons Related
Diamond Beech	Charioteer	10/09/1985	NTS	Tunnel	Weapons Effects
Roquefort	Charioteer	10/16/1985	NTS	Shaft	Weapons Related
Goldstone	Charioteer	12/28/1985	NTS	Shaft	Weapons Related
Mighty Oak	Charioteer	04/10/1986	NTS	Tunnel	Weapons Effects
Jefferson	Charioteer	04/22/1986	NTS	Shaft	Weapons Related
Panamint	Charioteer	05/21/1986	NTS	Shaft	Weapons Related
Darwin	Charioteer	06/25/1986	NTS	Shaft	Joint US-UK
Cornucopia	Charioteer	07/24/1986	NTS	Shaft	Weapons Related
Labquark	Charioteer	09/30/1986	NTS	Shaft	Weapons Related

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Table A6-1: Lawrence Livermore National Laboratory-Sponsored Atmospheric Weapons Tests, Underwater Weapons Tests, and Special Projects

Source: DOE 2000

Test Name	Operation	Date	Location	Type	Purpose
Belmont	Musketeer	10/16/1986	NTS	Shaft	Weapons Related
Bodie	Musketeer	12/13/1986	NTS	Shaft	Weapons Related
Hazebrook Emerald	Musketeer	02/03/1987	NTS	Shaft	Weapons Related
Hazebrook Checkerberry	Musketeer	02/03/1987	NTS	Shaft	Weapons Related
Hazebrook Apricot	Musketeer	02/03/1987	NTS	Shaft	Safety Experiment
Middle Note	Musketeer	03/18/1987	NTS	Tunnel	Weapons Effects
Delamar	Musketeer	04/18/1987	NTS	Shaft	Weapons Related
Hardin	Musketeer	04/30/1987	NTS	Shaft	Weapons Related
Brie	Musketeer	06/18/1987	NTS	Shaft	Weapons Related
Borate	Touchstone	10/23/1987	NTS	Shaft	Weapons Related
Mission Cyber	Touchstone	12/02/1987	NTS	Tunnel	Weapons Effects
Kernville	Touchstone	02/15/1988	NTS	Shaft	Weapons Related
Schellbourne	Touchstone	05/13/1988	NTS	Shaft	Weapons Related
Comstock	Touchstone	06/02/1988	NTS	Shaft	Weapons Related
Rhyolite	Touchstone	06/22/1988	NTS	Shaft	Weapons Related
Nightingale	Touchstone	06/22/1988	NTS	Shaft	Safety Experiment
Kearsarge	Touchstone	08/17/1988	NTS	Shaft	Weapons Related
Bullfrog	Touchstone	08/30/1988	NTS	Shaft	Weapons Related
Kawich A White	Cornerstone	12/09/1988	NTS	Shaft	Safety Experiment
Kawich A Blue	Cornerstone	12/09/1988	NTS	Shaft	Safety Experiment
Kawich A Red	Cornerstone	02/24/1989	NTS	Shaft	Weapons Related
Kawich A Black	Cornerstone	02/24/1989	NTS	Shaft	Safety Experiment
Ingot	Cornerstone	03/09/1989	NTS	Shaft	Weapons Related
Palisade 1	Cornerstone	05/15/1989	NTS	Shaft	Weapons Related
Palisade 2	Cornerstone	05/15/1989	NTS	Shaft	Safety Experiment
Palisade 3	Cornerstone	05/15/1989	NTS	Shaft	Safety Experiment
Contact	Cornerstone	06/22/1989	NTS	Shaft	Weapons Related
Disko Elm	Cornerstone	09/14/1989	NTS	Tunnel	Weapons Effects
Hornitos	Aqueduct	10/31/1989	NTS	Shaft	Weapons Related
Barnwell	Aqueduct	12/08/1989	NTS	Shaft	Joint US-UK
Metropolis	Aqueduct	03/10/1990	NTS	Shaft	Weapons Related
Bullion	Aqueduct	06/13/1990	NTS	Shaft	Weapons Related
Randsburg	Aqueduct	07/25/1990	NTS	Tunnel	Weapons Related
Tenabo	Sculpin	10/20/1990	NTS	Shaft	Weapons Related
Coso Bronze	Sculpin	03/08/1991	NTS	Shaft	Weapons Related

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Source: DOE 2000

Test Name	Operation	Date	Location	Type	Purpose
Coso Gray	Sculpin	03/08/1991	NTS	Shaft	Weapons Related
Coso Silver	Sculpin	03/08/1991	NTS	Shaft	Safety Experiment
Montello	Sculpin	04/16/1991	NTS	Shaft	Weapons Related
Hoya	Sculpin	09/14/1991	NTS	Shaft	Weapons Related
Bristol	Julin	11/26/1991	NTS	Shaft	Joint US-UK
Galena Yellow	Julin	06/23/1992	NTS	Shaft	Weapons Related
Galena Orange	Julin	06/23/1992	NTS	Shaft	Safety Experiment
Galena Green	Julin	06/23/1992	NTS	Shaft	Safety Experiment
Hunters Trophy	Julin	09/18/1992	NTS	Tunnel	Weapons Effects

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